INVESTIGATION OF PHOTO NEUTRALIZATION EFFICIENCY OF HIGH INTENSITY H$^-$ BEAM WITH ND:YAG LASER IN J-PARC*

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Abstract

The photo neutralization method with Nd:YAG laser for negative hydrogen ions has been expected as an available candidate for the transverse beam profile measurement. The fraction of photo detached electron can also be used for charge exchange procedure to extract very low power proton beam for Transmutation Experimental Facility in J-PARC. The laser system has advantages of maintenance and radiation hardness in high intensity proton accelerators. In order to establish the low power beam extraction system and beam profile monitor, the photo neutralization efficiency must be surveyed in practical beam line with high intensity H$^-$ beam. In this paper, an experimental set-up and preliminary results of photo neutralization method for intense H$^-$ beam in J-PARC MEBT1 are described.

INTRODUCTION

The J-PARC linac aims to provide high intensity negative hydrogen ion beams of peak current 50mA, kinetic energy 181/400MeV, pulse width 0.5mA and repetition rate 25Hz [1]. The goal of 133 kW beam power and hand-on maintenance will place significant demands on the performance and operational reliability of accelerator diagnostics systems. Beam diagnostics system is required to verify proper transverse focusing and matching of the magnetic focusing lattice of the linac. The transverse beam profile is one of the most important parameter for beam commissioning and/or tuning, and currently measured by single wire scanner in linac [2]. However, the interaction mechanism between thin wire and H$^-$ ions for various beam energies should also be investigated to clarify beam profiles. The photo neutralization method with Nd:YAG laser has been considered as an available candidate for beam intensity profile monitor. The photo neutralization technique is also expected as a beam extraction method for Transmutation Experimental Facility (TEF) in J-PARC [3]. The laser charge exchange method is an essential technique to extract very low power and narrow pulse width proton beam from intense H$^-$ beam as shown in Fig.1.

Thus, the neutralization efficiency should be investigated experimentally. This paper reports the development of a laser based beam profile monitor system. The MEBT1 beam diagnostic system to measure photo neutralization efficiency is also described in detail.

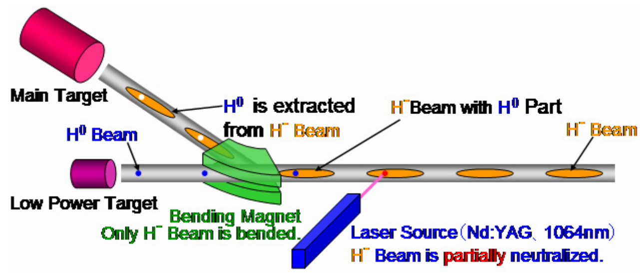

Figure1: Schematic view of low power beam extraction

EXPERIMENTAL SET-UP

The experimental device is composed of ion source, RFQ, MEBT1 and the laser system. A photo interaction chamber of laser profile monitor was installed in the MEBT1 (Fig. 2).

Ion Beam Line:

0.5ms long, 30mA pulse beam in the MEBT-1 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.

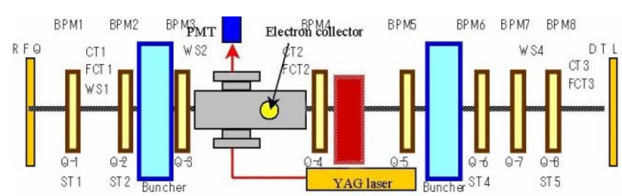

Figure 2: Laser profile monitor in MEBT1

Laser System:

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. Stripped electrons were deflected 90degree by an electromagnetic dipole and collected to a Faraday cup.

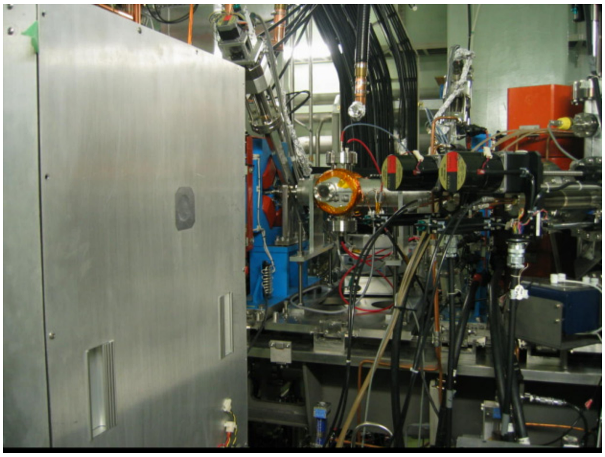

Figure 3: Layout of the laser injection port (center) and an optical beam guide box (left).

EXPERIMENTAL RESULTS

The beam current was also monitored by using a fast current transformer (FCT, ~324MHz) at downstream of laser diagnostic box [4].

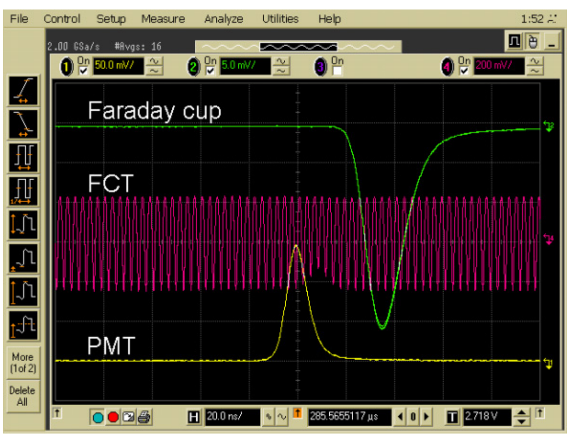

Figure 4: Example of Faraday cup, PMT and FCT signals during the laser injection timing.

The beam current notch was also measured 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 taking account of the total 31% through rate of electron reppeler and shield mesh, 3dB reduction of low pass filter and 50ohm input impedance of oscilloscope. As shown in Fig. 5, the consistent beam current notch level with neutralized electron signal was confirmed.

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.

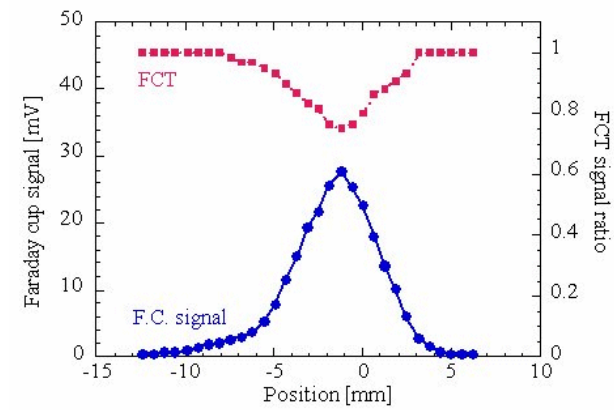

Figure 5: Faraday cup signal and FCT reduction profile in vertical direction (beam current 15mA). The FCT notch signal corresponds to stripped electron signal..

PHOTO NEUTRALIZATION EFFICIENCY

The fraction of beam ions neutralized by passing through the laser beam is,

$$f = 1 - e^{-\sigma(E)Ft}$$

Here σ(E) is the energy-dependent cross section, F is the photon flux, and t is the time during which the ion is in the laser light. For ion beam energies up to about 200MeV the cross section changes very little [1]. For example, the laser on the MEBT1 experiment produces a 20ns-long pulse with an output energy of 130mJ (repetition rate of 5Hz and taking into account the reduction of optical elements). It is formed to a laser spot 0.8mm hight by 6mm along the beam. The approximate variation of neutralization fraction with beam energy of this laser is shown in Fig.6.

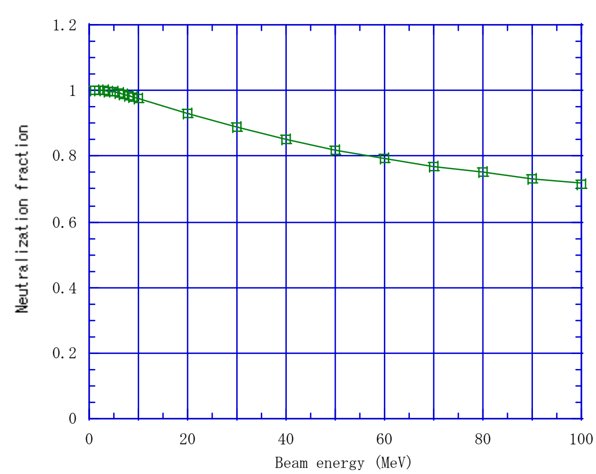

Figure 6: Calculated neutralization fraction as a function of beam energy for 20ns-long, 130mJ laser pulse focused to a spot size of 0.8mm x 6mm.

SUMMARY

The laser wire scanner using a pulse width of 20nsec, beam energy of 500mJ (repetition rate of 25Hz) Nd:YAG laser have been installed in J-PARC MEBT1 to measure current profile of high intensity H^- beam. It was confirmed that the photo stripped electron signal corresponds to the reduction of FCT current signal at downstream. The results of transverse profile measurements are also consistent with wire scanner signals of upper and downstream. The H^- beam components intercepted by 0.8mm height laser beam have been estimated by transverse profile measurement, and agree with photo detached fraction (Faraday cup and FCT reduction signal). The calculation results also show the complete neutralization ratio with 130mJ Nd:YAG laser for 3MeV H^- beam. 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 be confirmed practically. The difficulty of practical construction of laser system, for example the stability of optical transport line and/or laser oscillator, should be investigated in future.

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