Energy Analysis of a H$^-$ Beam Using Detached Electrons

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Abstract

An electron of a negative hydrogen ion (H$^-$) can be easily detached by collisions with an external laser beam or residual gas molecules in the beam line, because its electron affinity is small. The detached electrons provide information about the original H$^-$ ions. The detached electrons should have the same velocity as the original H$^-$ ions. By measuring the energy of detached electrons, the energy of a H$^-$ beam can be estimated. The preliminary experimental results of an energy analysis of a H$^-$ beam using detached electrons are presented.

1. Introduction

In the KEK 12 GeV proton synchrotron (KEK-PS), charge-exchange multi-turn injection with a negative hydrogen ion (H$^-$) beam has been used. Good matching between the longitudinal emittance of the injected beam and the longitudinal acceptance of the synchrotron is required to make beam acceleration efficient. For longitudinal matching, the central value of the energy and the energy distribution of the injected beam must be carefully measured. For this purpose, a magnetic energy analyzer at the injection beam line has been used in normal operation. In this scheme, however, there is a problem that during the measurement, the beam cannot be injected into the synchrotron.

Recently, the measurement of a photodetached electrons by the laser injection has been reported. By introducing a photon corresponding to the binding energy between the atom and the additional electrons, the electron of the H$^-$ ion is easily detached. To obtain information about the original H$^-$ beam, the detached electron or the atomic hydrogen should be measured. If external laser light has a short time width compared with that of a bunched beam from the injector linac, the energy distribution of the beam in each longitudinal position of the bunches can be measured.

We have developed a compact and simple device for an energy distribution measurement of a H$^-$ beam using detached electrons. Before using a laser, the energy measurement of detached electrons by gas detachment is carried out.

2. Experiment

An H$^-$ ion is an ion in which one electron attaches to a hydrogen atom and its electron affinity is 0.754 eV. The electron can be detached by collisions with residual gas atoms in the beam line. This detached electron has the same velocity as the original H$^-$ ion, if the energy transfer in the collision is negligibly small. The energy of the detached electron is smaller than that of the H$^-$ ion by 1/1838. Since the magnetic field strength needed to analyze this low-energy electron distribution is so small, there is no disturbance to the H$^-$ beam.

The energy analyzing system using gas cell is shown in Fig. 1. A preliminary experiment was made using the 750 keV pre-injector beam line. The pre-injector ion source was operated in the pulsed mode; the pulse H$^-$ beam had a width of 0.2 ms and a reputation of 20 Hz. Three acceleration energies (709.8 keV, 546.0 keV and 455.0 keV) were chosen. The beam intensity was kept at about 1 mA during the experiment. After a 30 degree bending magnet in the beam line, an analyzer magnet was installed inside the vacuum chamber. A small gas cell come installed in the beam pipe. Electrons coming from upstream of the beam line could be eliminated with the 30 degree bending magnet.

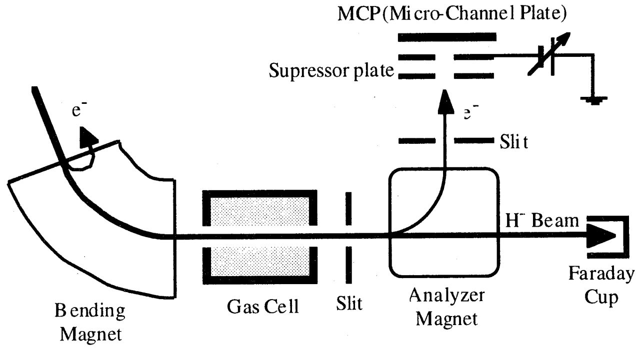

Fig. 1 Schematic diagram of the energy analyzing system for electrons detached from a H$^-$ beam using a gas cell.

Those electrons detached from H$^-$ ions in the H_2 gas cell were deflected by the analyzer magnet. The detached electrons were measured by MCP (Micro-Channel Plate). A plate in front of MCP was installed. By applying a negative voltage to this plate, the energy distribution of the detached electrons was measured. A small Faraday cup was installed stream down of the chamber, and the intensity of H^- beam current was monitored during the experiment. Two turbo-molecular vacuum pumps were installed.

3. Experimental results and discussions

In a preliminary experiment, the output signal from MCP was measured as a function of the H^- beam energy, by changing of coil current of analyzer magnet from 0 A to 1 A. The suppressor voltage for the low-energy electrons in front of MCP was set to -150 V. When H_2 gas was introduced into the cell (P_{cell}= $1x10^{-5}$ Torr), a sharp peak of the detached electrons was observed, as shown in Fig. 2. The position of this peak

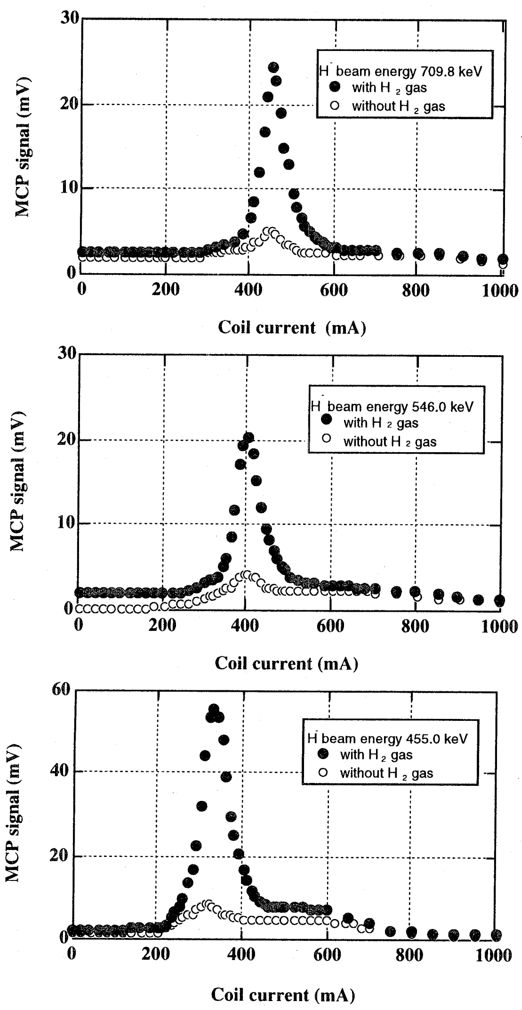

Fig. 2 Characteristics of the MCP signal by changing the coil current of the analyzer magnet.

depended on the energy of the H^- beam. An energy measurement of the detached electron was achieved by a retarding method. The coil current of the analyzer magnet was fixed to obtain a peak of the detached electrons as shown in Fig. 2. Then, the suppressor voltage was swept from 0 V to -500 V to observe the energy distribution of detached electrons. The MCP signals when the hydrogen energies were 709.8 keV, 546.0 keV and 455.0 keV, respectively is shown in Fig. 3. The differentiated values of the data of Fig. 3 is shown in Fig. 4.

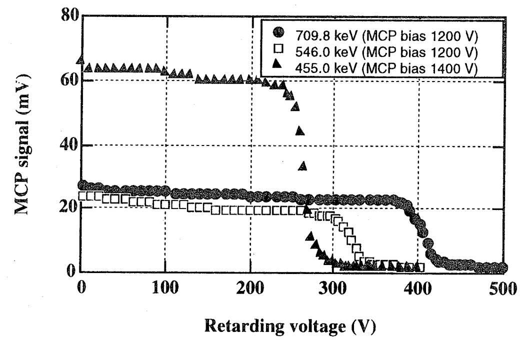

Fig. 3 Characteristics of the MCP signal by changing the suppressor voltage.

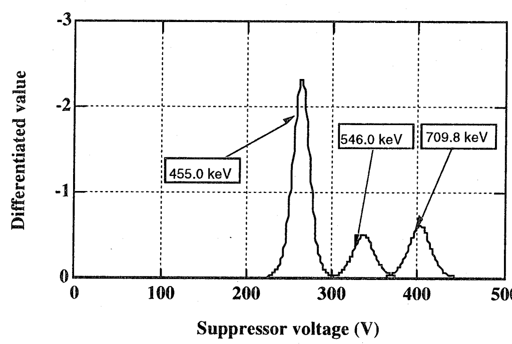

Fig. 4 Differentiated value of the data in Fig. 3.The peak of the differential curve appeared at a suppressor voltege of 404.2 V in the case of 709.8 keV. The suppressor voltages were found to be 338.8 V and 265.8 V, in the cases of H^- beam energies of 546.0 keV and 455.0 keV, respectively.

The detached electrons energies measured by the retarding method for various H^- beam energies. The linearity between the energies of the detached electrons and the H^- ions seems to be well within the errors. In this analysis, we neglected the energy transfer effects at collisions between H^- ions and H_2 gas molecules. This may be supported because we have measured very forward-direction electrons. In the future measurement using laser beam, this situation will be improved.

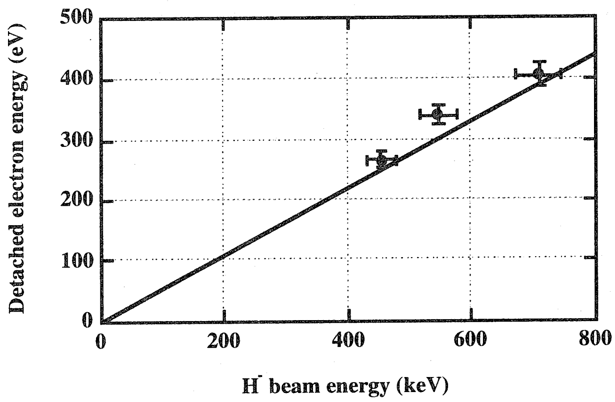

Fig. 5 Correlation between the H^- beam energy and the detached electron energy obtained by the retarding method. The inclination of the solid line is the ratio of an electron to an H^- ion. The plotted points are the data obtained from Fig. 4.

4. Conclusion

A simple apparatus enabled the use of a detached electron to perform an energy analysis with an error of less than 5 % by this experiment. By this device, we could easily observed detached electrons from a H^- beam by the residual gas method. Furthermore, simulations are planned to explain the gas detachment mechanism. An improvement in the energy analysis with the retarding method is required to perform better measurements.

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