The Beam Diagnostic System for the JAERI AVF Cyclotron

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Abstract

This paper describes the beam diagnostic system for the JAERI AVF cyclotron. Thirty six stations equipped with various diagnostic devices are distributed over the beam transport lines of the cyclotron, and several radial probes are installed inside the cyclotron. Additional beam diagnostic methods have been applied for the measurements of the various beam characteristics required by beam applications and the beam study of the cyclotron.

1. INTRODUCTION

The JAERI AVF cyclotron (K=110)[1] has been constructed in 1991 for advanced radiation application to wide fields of R & D: materials for space environment and nuclear fusion reactors, biotechnology and new functional materials. In order to meet the requirements of the fields, the cyclotron was designed to accelerate various ions of proton to xenon in a wide range of energies up to 90MeV in proton, and to provide characteristic beam applications: uniform irradiation over a large area, pulsed beam irradiation, secondary produced neutron beams, etc..

In these applications, more frequent beam tuning than in fundamental physical experiments is required to change the beam energies, the target ports, accelerating ions, etc.. To tune and transport the various beams quickly, standard diagnostic stations equipped with different beam diagnostic devices were installed in the beam line. Radial beam monitors were also installed inside the cyclotron to make a diagnosis of the acceleration condition such as radial distributions of the beam intensity.

The above beam applications require to monitor and tune the beam characteristic according to the special purpose of each experiment. The pulsed beams are applied to various experiments such as in-situ analyses of elementary process in interaction of ions with material, time of flight experiments and characterization of the cyclotron beams. A beam pulse monitor with a micro channel plate (MCP) has been developed to provide time information on the beams. The uniform irradiation of high-energy, intense beams over a large area is required for testing radiation resistance of organic materials and solar cells. Two-dimensional beam scanning systems allow uniform irradiation over the field size of 100 x 100 mm^2. The fluence distribution of the irradiated area was measured by cellulose triacetate (CTA) dosimeter[2] based on the radiation induced optical density change in the film. However this method cannot give fluence distribution in real-time. We have applied a parallel plate avalanche counter (PPAC) to the monitor of the fluence distribution.

2. DIAGNOSTIC SYSTEM FOR BEAM TUNING

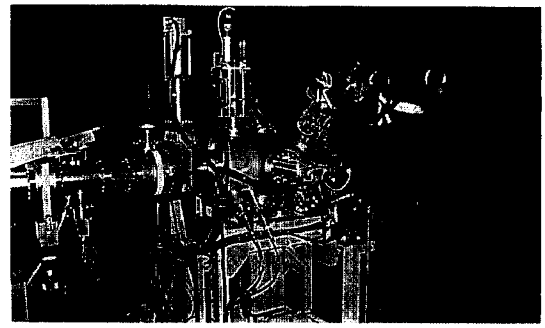

Figure 1. An example of a diagnostic chamber equipped with diagnostic devices in the external beam line.

2.1 Injection and external beam diagnostics

The standard diagnostic chamber was adopted to install beam diagnostic devices at the waist point of the beam. It is very efficient for beam tuning in the beam transport lines to monitor beam intensities, beam positions and beam profiles at the waist points. Each chamber is equipped with a standard set of beam diagnostic devices: a set for the injection beam line consists of a Faraday cup, a profile monitor and a slit system, and another set for the external beam line consists of the above three devices and an alumina monitor. A diagnostic chamber installed in the external beam line is shown in Fig. 1.

The Faraday cup is of cylindrical-shaped with a suppressor ring biased at -500 V. In the injection line, a tantalum plate is mounted on the bottom of the cup for protecting ion sputtering by the low-energy intense beams. The cups for the external line were designed to stop 90 MeV proton beam and to withstand the beam power of 3 kW. All the Faraday cups are used not only as beam intensity monitors but also as beam stoppers in the safety interlocking system of the cyclotron.

The profile monitors were used to monitor the cross-sectional beam intensity distribution in three different directions: horizontal, vertical and 45° directions. The beam profiles are measured by scanning three gold-plated tungsten wires of 0.1 mm in diameter.

The alumina monitor using an Al_2O_3 plate gives a beam profile. A TV camera is mounted below the diagnosis chamber to catch the scintillation image on the Al_2O_3 plate tilted at 45° against the beam axis through the viewing port.

The slit system consists of a pair of units for vertical and horizontal directions. The one unit is mounted opposite to another one on a flange of the diagnosis chamber in direction at 45° to the vertical axis. Each tip is a 3 mm thick tantalum plate for the injection line and a 14 mm thick copper one for the external line.

Two beam emittance monitors were installed at the exit of the analyzing magnet of the ECR ion source and at the exit of the cyclotron. Each monitor consists of a slit to define the beam position and a multi-wire detector to measure the range of the angular divergence.

A beam current monitor with a rotating tungsten rod of 0.5 mm in diameter, was installed in the external line. The beam intensity distribution in the horizontal direction, measured with a rotating rod, is integrated to get the total beam intensity.

2.2 Internal beam diagnostics

Inside the cyclotron, three kinds of radial probes are installed to measure the beam intensity distribution. A main radial probe covers the distribution in the whole acceleration range from 40 mm to 1190 mm. The probe head consists of three finger-like tantalum electrodes arrayed vertically for the differential measurement and a water-cooled copper electrode for the integral measurement. The differential electrodes jut 0.7 mm out of the integral one. A deflector probe, located in front of the entrance of the deflector, has an integral and a differential electrodes, providing the beam intensity distribution just before the extraction. A magnetic channel probe with a single probe head provides the beam intensity before and after the beam passing through the deflector.

A fixed slit system composed of four tips was mounted just before the entrance of the cyclotron to tune the axially injected beam. Other three fixed slit system were mounted on the magnetic channel, the gradient corrector and the exit of the chamber.

In addition to above probes, ten pairs of capacitive phase probes were installed along a radius for measuring relative phases of the beams on different turns. Each phase probe has a couple of copper plates arranged in parallel with each other.

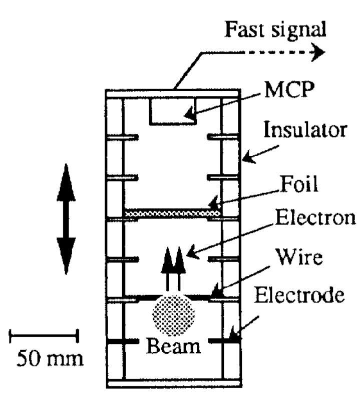

Figure 2. The structure of the Beam Pulse Monitor

3. MEASUREMENTS OF BEAM CHARACTERISTICS

3.1 Beam pulse measurement

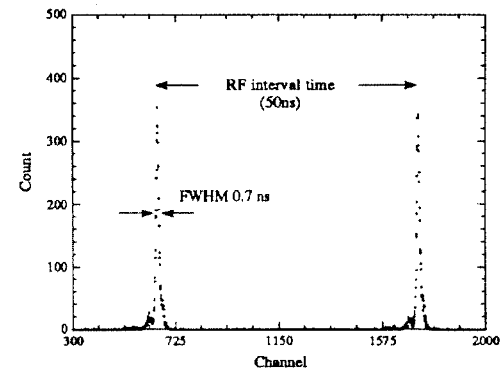

Figure 3. An example of time spectra measured for $^{20}Ne^{8+}$ 350 MeV by using the start signal from the monitor and the stop signal from the divided RF signal of the cyclotron.

The pulsed beam experiments require non-destructive methods to monitor the beam during the beam experiments, and high sensitivity to a wide variety of beams of from proton to heavy ions in wide ranges of the energy and the beam intensity.

For these reasons, we have developed a highly sensitive beam pulse monitor using a MCP with a high signal gain and high time resolution. The pulsed beam can be detected by secondary electrons emitted from a inserted target when the beam passing through it[3].

The monitor consists of an assemble type MCP (F4655-10, Hamamatsu photonics Ltd.), seven sets of electrodes spaced by insulator rods (Al_2O_3) and targets for the secondary electron emission. These targets consist of a tungsten wire 0.3mm in diameter for heavy ion beams and a 3 μm thick aluminum foil tilted at 45° against the beam axis for light ion beams. The structure is shown in Fig. 2. The monitor is driven by a stepping motor to adjust the target position. The secondary electrons emitted from a target are guided onto the MCP by an electrostatic field biased up to -10kV. The wire and the foil are stretched in parallel with the MCP, but the position of the foil is shifted horizontally not to disturb the secondary electrons from the wire. Amplified fast signals are provided from the MCP with high counting rate more than 10 kcps. The entrance face of the MCP and the surface of the wire and the foil were evaporated with CsI to increase the emission of the secondary electrons[4]. The monitor allows almost non-destructive monitoring by selecting the targets and adjusting the target position to keep the high quality of the beam.

An example of the time spectra obtained by the monitor is shown in Fig. 3 for the preliminary test using a $^{20}Ne^{8+}$ 350 MeV beam. In this experiment, the foil was located at the center of the beam. The time spectrum was measured by a time-to-amplitude converter using start signals from the counter and stop signals from the divided RF signal of the cyclotron.

This monitor can also provide the beam intensity distribution by replacing the MCP with a multi-anodes type one equipped with 32 strips of 1.7 mm pitch. The target scan allows to provide two-dimensional beam intensity distributions.

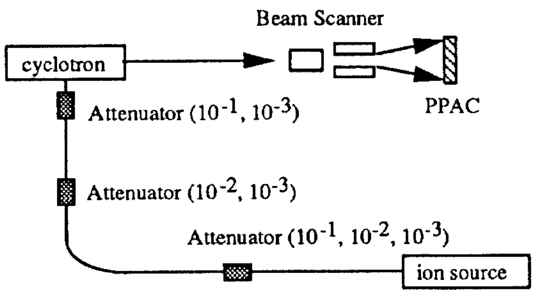

Figure 4. The layout of the fluence distribution measurement system. Three attenuator were installed in the diagnosis chambers in the injection line.

3.2 Measurement of fluence distribution

Fluence uniformity and reproducibility are required in ion beam irradiation to wide targets for radiation resistance test and ion implantation. To monitor a two-dimensional fluence distribution on the target, we are developing a real-time fluence rate mapping system for a large area. In the first place, we have developed a parallel plate avalanche counter (PPAC)[5] with a large sensitive area. The PPAC has been used mainly in the nuclear physics experiments. Drastic beam intensity attenuation was needed to match the beam intensity to the available counting rate of the PPAC. Three beam attenuators installed in the injection line allow to reduce beam intensity at the ratio of less than 10^{-9}. Each attenuator consists of two or three meshes, each with a hole ratio of 10^{-1}, 10^{-2} or 10^{-3}. The layout of the system is shown in Fig. 4.

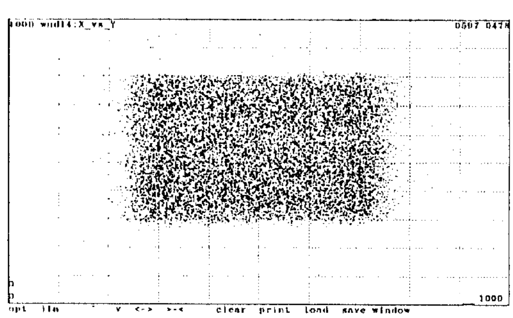

Figure 5. An example of fluence distributions measured by the PPAC. A $^{20}Ne^{7+}$ 260 MeV beam was scanned in the area of 50 x 50 mm^2. A unit in horizontal and vertical directions is 11mm.

The PPAC can detect the incident positions of the particles within the region of 120 x 120 mm^2 by the charge division method. It has one anode sandwiched between two cathodes. The anode is a 4 μm-thick Mylar film of which the both sides were evaporated with a gold layer 40 μg/cm^2 thick. The cathodes are also a 4 μm-thick Mylar film of which the inner sides were evaporated with a gold layer 80 μg/cm^2 thick has 80 strips of 1.25 mm wide with 0.25 mm spacing. Each strip is electrically connected to neighbor one by a resistance of 510 ohm. These electrodes were enclosed by a small chamber filled with isobutane gas at a pressure of 10 torr. An example of fluence distributions measured by the PPAC is shown in Fig. 5.

4. REFERENCES

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