DEVELOPMENT OF BEAM PROFILE MONITOR FOR HIMAC

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Abstract

Heavy ion beam profiles are monitored by integrating signal current being generated on a wire of a multiwire proportional chamber(MWPC) consisting of two planes. Each plane has 32 horizontal or vertical wires. The multiwire chamber was built and operated by letting a mixed gas of Ar(80%) and CO_2(20%) flow continuously through the chamber. It was tested by using 70 MeV proton beams at the National Institute of Radiological Sciences(NIRS). Total performance of the MWPC was proved effective with the proton beams of 0.1pA ~ 10nA.

Introduction

Heavy ion beams will be accelerated at the Heavy Ion Medical Accelerator in Chiba(HIMAC), and used as radiotherapy for various kinds of cancer at NIRS. The heavy ion beams give high LET radiations, so several ions between helium and argon are proposed. The maximum energy is 800 MeV/u. Heavy ion beam intensities are relatively low in comparison with usual proton beam intensities. Radiotherapy requires a suitable monitor which possesses a wide intensity range in order to detect correctly. One of the most suitable monitors is a gaseous detector because of its gas multiplication, which helps to obtain a wide intensity range.

The beams have to be tuned spatially with better than 1mm accuracy so as to deliver and irradiate beams on patients correctly. At present 29 beam profile monitors will be placed along high energy beam transport lines(HEBT) totalling about 300m long.

Output signals of the monitors are converted to digital signals, and sent to I/O ports of a HEBT control system via RS422 transmission lines.

Based on techniques from high energy physics experiments[1], we built a multiwire proportional chamber as a beam profile monitor and tested by using 70 MeV proton beams at NIRS. The results of these tests are described here.

Basic Design of the Beam Profile Monitor System

MWPC

The basic design goal of the MWPC was to obtain a wide intensity range in order to monitor profiles of various kind of beams. The range of beam intensities to be used for therapy spans 5 orders of magnitude from $1 \times 10^6 \sim 1\times10^{11}$ pps, which are helium beam equivalent intensities. The MWPC has two orthogonal signal wire planes. Each plane has 32-wire. The anode wires are spaces 2 mm apart, thus the effective area of the plane is 64 mm x 64 mm. Cathode planes also consist of wires. The anode wire is 20 μm W, and the cathode wire is 50 μm Be-Cu. The anode-cathode gap is 4 mm. Table 1 shows the dimensions of the MWPC. An outline of the MWPC is shown in Fig.1. An approximate formula of Diethorn[2] predicts a gas multiplication of gaseous detectors by using a few parameters. Some of these parameters are dimensions of MWPCs, and the others are characteristic constants of gases. Fig. 4 shows calculated values of gas multiplication factors for the MWPC using P-10 gas.

In tests mentioned later, the mixed gas of Ar(80%) and CO_2 (20%) was used. The gas flowed continuously through the chamber. Safety regulations required the use of an inflammable gas, not a flammable gas like P-10 gas, in case some gases leaked into the room. The mixed gas of Ar and CO_2 is one of the best inflammable gases. Differences between Ar-CO_2 (20%) gas and P-10 gas are discussed later.

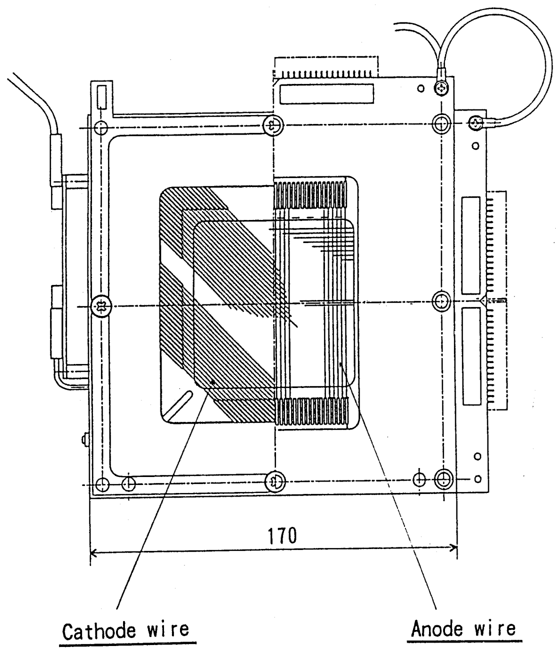

Fig.1. A schematic of the MWPC.

Table 1.
Dimensions of the MWPC

Effective area:	64 x 64 mm^2
Anode-wire spacing:	2 mm
Anode-cathode gap	4 mm
Wire diameter, Anode:	20 μm
Cathode:	50 μm
Number of anode-wire:	32
Material of wires, Anode:	Au plated W
Cathode:	Au plated Be-Cu

Chamber electronics

Generated current on a wire of the MWPC was integrated on a capacitor in the integration circuit in the interval 50 msec ~ 1sec (Fig.2). An external trigger signal gives the chamber electronics a timing signal to begin integration at arbitrary moment in a beam pulse. The trigger signal also controls the time width of integration. Henceforth, we shall call the time width of integration the "integration time".

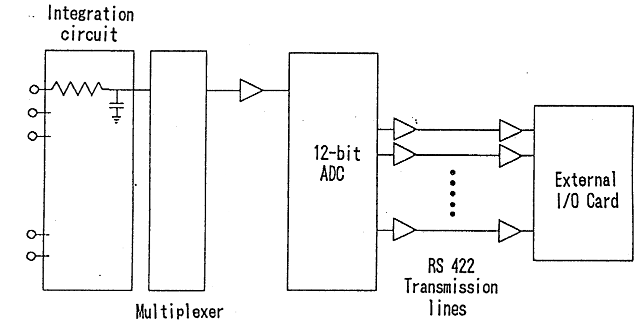

Fig.2. A block diagram of the chamber electronics and external I/O cards.

The analog signal of 10 V of the full scale is converted to a 12-bit digital signal. Parallel 12-bit digital signals are sent in a sequence of 64 profile-data to an external I/F card of the HEBT control system through RS 422 transmission lines.

Tests of the MWPC

Setup and condition of the tests

The MWPC was installed in a vacuum chamber at the end of a beam line at the NIRS cyclotron. The MWPC was plunged into the beam line by an air cylinder. Continuous proton beams extracted from the cyclotron impinged on the wires through a 0.3 mm thick aluminum window. The beams got through the end of the beam pipe and stopped at the 1 cm thick copper plate behind the end of the beam pipe. At this point the beam current was measured.

A proton beam of 70 MeV loses energy of 9 keV in an 8 mm thick layer of Ar-CO_2(20%) gas. A helium beam of 800 MeV/u loses energy of 4 keV. Therefore one proton of 70 MeV ionizes about twice as many molecules of atoms of the gas as a helium ion of 800 MeV/u. The proton beam of 0.1 pA to 10 nA corresponds to 1.35×10^6 to 1.35×10^{11} pps of the helium beam.

The chamber electronics were located near the MWPC to prevent noise. After the ADC, 60 m twisted-pair cables were used to send digital signals from the experimental room to the control room. A high voltage power supply was put in the control room, applying high voltage to the MWPC with a 70 m coaxial cable.

The chamber electronics were grounded to the beam pipe. This grounding made the electric level of the MWPC's guard rings and the outer shield of HV cable the same level of the beam pipe. It worked well for reducing noise on the MWPC system.

The 12-bit digital signals were sent to the control room, and converted to analog signals again in order to observe the beam profiles with a digital oscilloscope.

Results

For the tests we listed items to be checked as follows,

(1) Noise level at the control room via 60 m cables.
(2) Gas multiplication factor of the MWPC.
(3) Space charge effect at high beam-intensity.
(4) Intensity range for monitoring beam profiles/ adjustability

Typical noise level was 1 ~ 3 digits of full 4096-digit. In most cases the noise did not bother the observation of the beam profile. But without grounding to the beam pipe, about 200 mV of common mode noise folded on the signal was observed at the experimental room. An example of a beam profile is shown in Fig.3.

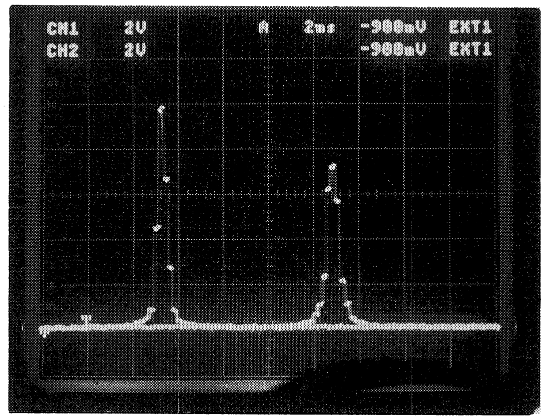

Fig.3. An example of proton beam profiles.

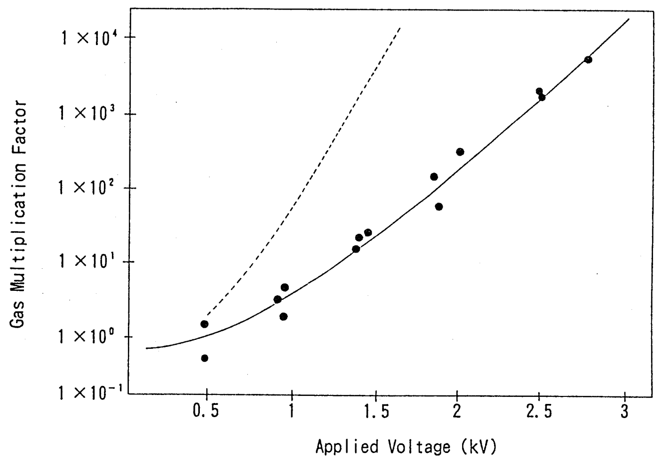

Fig.4. Gas multiplication factors of the MWPC.
(a) Solid circles : Experimental data.
(b) Solid line : Fitted curve to the experimental data.
(c) Dotted line : Calculated values with P-10 gas.

In Fig.4, the gas multiplication factor is shown vs. applied voltage to the cathode. The gas multiplication factor was derived from comparison with the integrated charges and the initially produced charges at the first ionization, calculated with the aid of Beth-Bloch's formula. Beam currents were given by the beam stopper as mentioned above. The data were taken at beam intensities of 700 pA, 100 pA, 7 pA, 0.7 pA and 0.06 pA. The lower multiplication factor was derived from the higher intensity data, and vice versa.

Space charge effects are supposed to be observed as deformations of beam profiles. Because FWHM characterizes the shape of the profile, deformation can be easily found by checking a change of FWHM. All FWHMs which were observed at the intensities mentioned above and at various applied voltages were 3 ~ 4 wire-pitches. There was no systematic change in the FWHMs.

For a higher intensity beam, such as the 10 nA proton beam, the MWPC can be operated in the ionization chamber region, or by applying lower voltage. In the case of the 10 nA proton beam, lowering the applied voltage was not enough to observe the beam profile correctly without ADC saturation. Therefore, we shortened the integration time by 100 msec or a less to make the peak height of the beam profiles less than or equal to 10 V. In Fig.5 the intensity range for helium beams is summarized with respect to the applied voltage and the integration

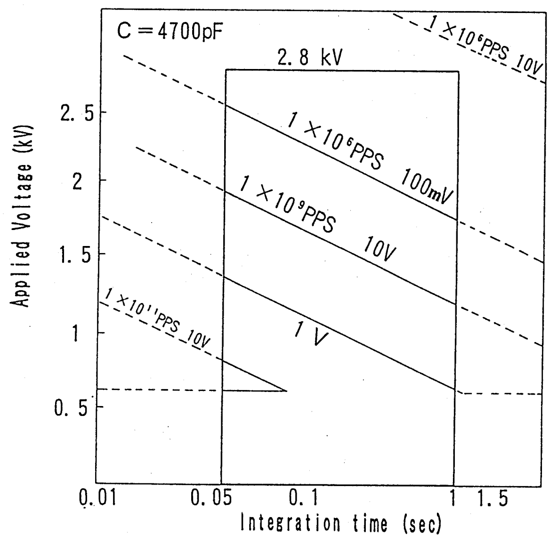

Fig.5. Intensity range of the MWPC for helium beams. The skewed lines show contour lines of given peak voltages of beam profiles.

time. An approximate formula was used to estimate peak heights of beam profiles at given integration times. The formula approximately reproduces the data of 100 pA proton beams at the integration time of 200 ms. It is as follows,

$$V_{out} = 0.0204 \, Exp(-4.02 \, V)$$

where V is the applied voltage (kV) and V_{out} is the signal voltage at the integration time of 200 ms.

Discussion

In Fig.4 the data are fitted by a solid-line curve derived from Diethorn's formula[3]. In this fitting we treated ΔV and K in the formula as free parameters. The numerical values are ΔV = 55.5 eV and K = 5.7 x 10^4 V/atm/cm. Comparing the curve calculated with P-10 gas and the fitted curve, it was found that the gas used in these tests gives lower multiplication factor than P-10 gas at a given applied voltage. This result is shown in the ΔV parameter, which is larger than those of other gases. Increasing the ratio of Argon with respect to CO_2 causes multiplication factor to increase. But the voltage at which discharge between anode wires and cathode wires occurs will decrease. The discharge at lower voltage makes operation difficult.

According to the estimated intensity range, this MWPC system has wider coverage at the lower intensity beam. At the highest intensity beam of 1 x 10^{11} pps, there is smaller coverage. The capacity C of an integration circuit changes this situation. Output voltage is derived from the equation V_{out} = Q/C, here Q is an integrated charge. Enlarging the value of C would shift the intensity range toward the higher intensity region.

Summary

We summarize the results of the MWPC and these tests as follows.

(1) The MWPC worked well with respect to the proton beams in the region of 0.1 pA to 10 nA without deformation of beam profiles. These intensities correspond to helium beams of 800 MeV/u at 1.35 x $10^6 \sim 1.35 \times 10^{11}$ pps.

(2) Improvement of the chamber electronics is necessary to shift the intensity range to cover higher intensity region.

(3) The gas mixture Ar (80%) CO_2 (20%) is suitable for giving the high gas multiplication factor, and for safety regulations.

(4) Grounding to the beam pipe reduces the common mode noise.

Acknowledgements

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