PA40

Continuous Beam Monitoring for Charged Particle Therapy

M.Torikoshi, H.Ogawa, K.Noda, E.Takada, T.Kanai,
K.Narita*, T.Fukuzumi*, T.Kohno**

National Institute of Radiological Sciences, 4-9-1 Anagawa, Chiba 263, Japan
*Accelerator Engineering Corporation, Konakadai, Chiba 263, Japan
**Department of Energy Sciences, Tokyo Institute of Technology, 4259 Nagatsuta, Yokohama 226, Japan

Abstract

Continuous beam monitoring can ensure beam stability during beam irradiation for charged particle therapy.It can also detect the beam which is not synchronized with a patient's respiratory in case of treatment of an organ moving with respiratory. A MWPC was adapted to these purposes. It was used in air not to disturb beam. The effective thickness of the MWPC with respect to the beam is only that of wires. Therefore, scattering the beam and losing the energy of the beam in the MWPC is sufficiently small so that they do not affect charged particle therapy. The MWPC was proved to be useful by use for biology experiments.

Introduction

The Heavy Ion Medical Accelerator in Chiba (HIMAC) at National Institute of Radiological Sciences is the first heavy ion accelerator complex dedicated for charged particle therapy[1,2]. Charged particle therapy severely requires controlling dose of beam and safety assurance. In the HIMAC, the dose is measured by using two monitors, an ion chamber and a secondary electron monitor, at the same time. Occurrence of any abnormal conditions interlocks the beam irradiation through a global interlock system.

Furthermore, the continuous beam monitoring is one of strong means to ensure beam quality as follows. The first is assurance of stability of beam profile and position, because they affect beam intensity distribution at an isocenter. The second is detection of the beam which is not coincident with a patient's respiratory during the treatment of an organ moving with the respiratory. When such a beam spill is detected, the treatment is interrupted in order to make beam extraction coincident with the respiratory. Thus the continuous monitoring shall be one of the activities of quality assurance for the charged particle therapy.

Beam monitor for medical use

A multi-wire proportional chamber was in use for the continuous monitoring. The MWPC is same as that developed for beam monitors used at the high energy beam transfer lines (HEBT) of the HIMAC[3]. A picture of the MWPC is shown in Fig.1.

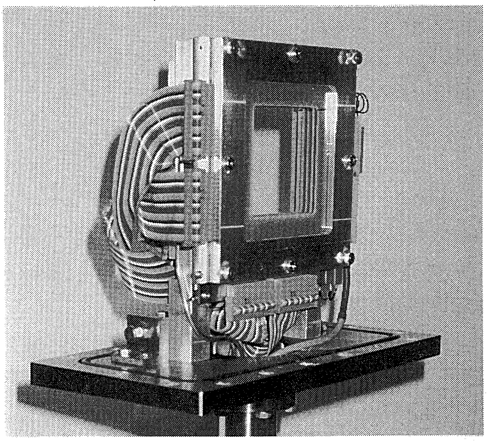

Fig.1 MWPC used in air

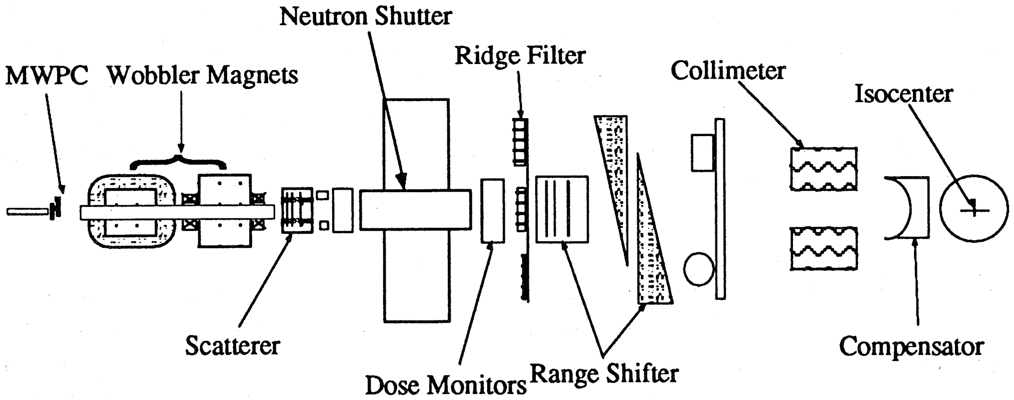

Fig.2 Configuration of the BIOLOGY beam course

Rare gases or organic gases are generally used to obtain high amplification factor of the MWPC. In these cases, thin windows are necessary on the MWPC to have gas tight structure. Our purpose is focusing to use the MWPC as a sort of non-destructive monitors, so that the MWPC should have no window on it. Eventually, air is used as the sensor gas of the MWPC. Therefore the beam passing through the MWPC has a probability to collide with only the wires. We describe the effects of the collision as an average thickness of the wires, that is approximately $8 \times 10^{-2} g/cm^2$. This is corresponding to water equivalent thickness of only 0.8mm. This value is negligibly small in comparison with thickness of a margin on a target volume in a body.

The MWPC was installed at the end of BIOLOGY beam line as shown in Fig.2. The MWPC is located between the end of beam duct and Wobbler magnets. The beam intensity is uniformly distributed at the isocenter by a pair of Wobbler magnet and a scatterer. Each wobbler magnet sweeps sinuously the beam in horizontal or vertical direction. Combination of both motions of the beam results in rotational motion. The rotating beam is scattered by the scatterers. In this way, the beam of maximum diameter 22cm become uniform within ±5% at the isocenter. Scattering effect at the MWPC affects the uniformity. However, the effect evaluated by a calculation is only less than 1×10^{-3}%. Eventually the MWPC can be regarded as the non-destructive monitor for the charged particle therapy.

Electronics

We used the same electronics with that used for the beam profile monitors of the HEBT[3]. Generated current on a wire of the MWPC is integrated on a capacitor in the integration circuit.

The electronics gives us good performance as follows. Typical noise level is 1 digit of full scale 2048-digit. The noise level is independent of the time width of integration. It means that leak currents in electronic elements do not contribute to the noise, or are very small. A simple estimation shows that the leak currents are supposed to be less than 0.1nA each channel. Cross talk between adjacent channels is less than -60dB. Because of the low noise level and the small cross talk, the beam profiles can be observed clearly even though the peak height of the profile is less than 0.1V.

Tests and results

In order to test the MWPC under various beam conditions, the MWPC was installed in BIOLOGY beam course as mentioned above. The BIOLOGY beam course is used for biology experiments and not therapy.

Fig.3 shows dependence of the gas amplification factor on applying voltage. It was measured at C^{6+} 290MeV/u beam. The amplification curve is normalized

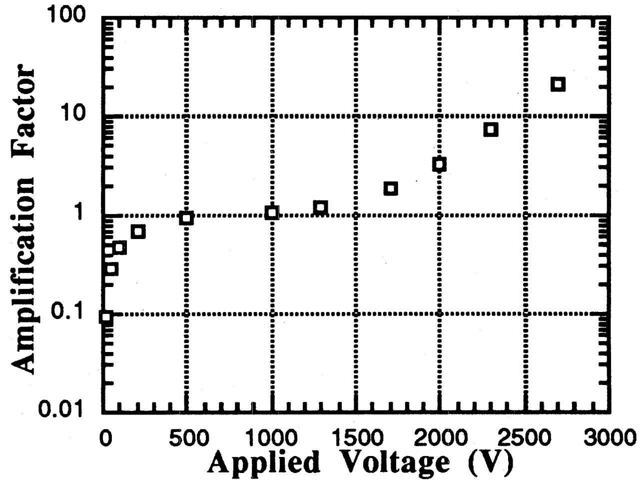

Fig.3 Dependence of amplification on applied voltage

to 1 at plateau region. Because the amplification factor should be 1 at the plateau region. The curve shows the amplification factor is about 20 at -2.7kV the maximum voltage of the MWPC. The amplification factor 20 is small compared with that of same type profiles monitors used at the HEBT. They gain more than 5,000 filling with Ar-CO_2 mixed gas[4]. Comparatively small amplification factor results from quenching effect due to oxygen. An oxygen component of air strongly quenches electron avalanche even under a considerably strong electric field. Charged particle therapy is performed using the beam intensity of $3.6 \sim 3.2 \times 10^8$pps. In order to observe such a beam, the MWPC does not need to obtain a wide intensity range. This condition does not require the MWPC to have high amplification factors.

Dynamic range of this MWPC system spans from 1 to 2,000. This results from that the range of amplification factor of the MWPC is from 1 to 20, and the dynamic range of the electronics is from 0.1V to 10V as mentioned already. Then the intensity range of observable beams is estimated, for instance of C^{6+} 290MeV/u beam, to be from 3×10^6pps to 6×10^9pps. It is sufficiently wide to cover the intensity range necessary for charged particle therapy or related measurements except for measuring LET.

A beam profile of C^{6+} 290MeV/u beam observed by the MWPC is shown in Fig.4. The MWPC is located at downstream from the last triplet quadrupole magnets of the BIOLOGY beam course. The triplet quadrupole magnets are forming 10mm diameter beam at the isocenter 11m downstream. Therefore, the beam has an approximate round shape as shown in the figure.

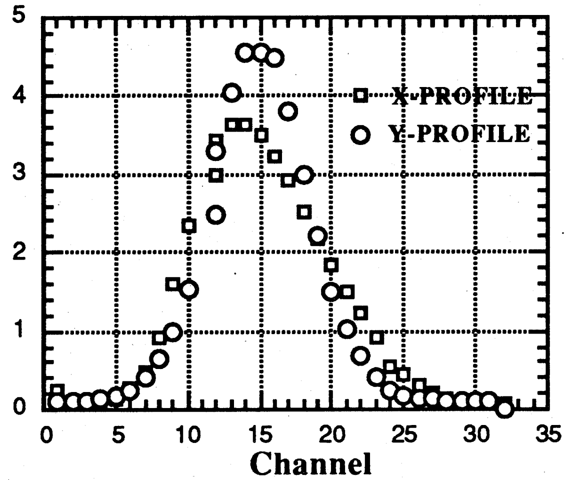

Fig.4 Beam profiles

A range of He^{2+} 150MeV/u beam in water was measured by using a water column. The measurements were carried out with and without the MWPC in the beam course. Both results are plotted in Fig.5. Circles indicate the results of the measurement with the MWPC, and squares indicate those without the MWPC. Difference between both Bragg peak positions was not detected. It means the difference is less than position resolution of the measurement.

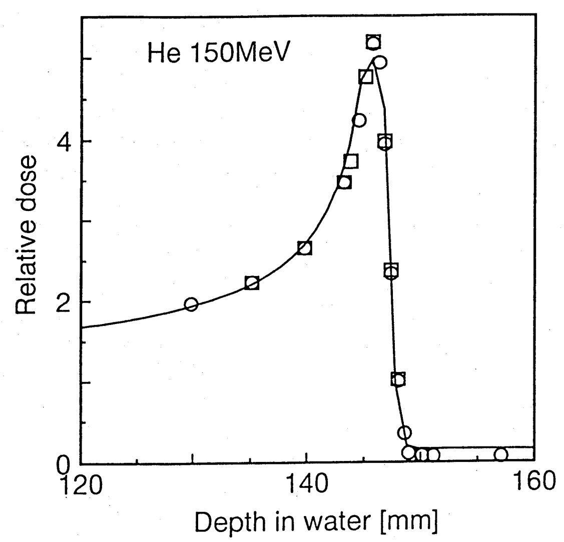

Fig.5 Dose spectra measured with and without the MWPC. Circles show results of with the MWPC.

Although an exposure of a film to the beam and scanning the density measured the beam uniformity, difference of the uniformity was undetectable as expected.

High voltage of -1kV was continuously applied to the MWPC for about 3 months. An approximate amount of total beams was 1.3^{14} particles. No damage due to radiation is found on the MWPC at present.

Conclusions

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

(1)The MWPC worked stably in air and gained the amplification factor of about 20 at -2.7kV. The total dynamic range including that of the electronics is from 1 to about 2,000. It is sufficiently wide to monitor the beam for charged particle therapy and related measurements.

(2)Disturbance of the beam was negligibly small so that it was supposed not to affect charged particle therapy and related measurements.

We do not test the MWPC to detect the beam which is not synchronized with a patient's respiratory, because the irradiation coincident with a patient's respiratory is in a test stage at present. However, we know that the response of MWPC is sufficiently fast to interrupt the irradiation within acceptable dose ambiguity.

We can conclude the MWPC system is working as a non-destructive beam monitor with versatility to ensure the quality of treatment. A damages due to radiation of a long term, however, must be watched continuously in future.

Acknowledgment

We would like to express our gratitude to the other members of Research Center of Charged Particle Therapy of NIRS for helpful discussion. We also wish to thank the members of Accelerator Engineering Corporation for their warm support.

References

1. K.Sato et al., "Status report on HIMAC", Proc. 4th European Particle Accelerator Conf., London, 1994

2. S.Yamada, "Commissioning and performance of the HIMAC medical accelerator", Int. Conf. on High Energy Accel., Dallas, 1995, to be published

3. M.Torikoshi et al., "Development of beam profile monitor for HIMAC", The 8th Symp. on Accel. Sci. and Tech.,Saitama, 1991, pp.317-319

4. M.Torikoshi et al., "Performance of beam monitors used at a beam transport system of HIMAC", Beam Instrumentation Workshop, AIP Conf. Proc. 333,Vancouver, 1994, pp.412-41