Beam-Ripple Monitor with secondary electrons

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Abstract

To replace the scintillation-ripple monitor, we have developed a new monitor with a smaller destructive effect on the beam. In this monitor, we use secondary electrons emitted from an aluminum foil with a thickness of 2μm. The signals of secondary electrons are amplified by an electron multiplier having a maximum gain of 10^6. By using the new monitor, we could clearly observe the beam ripple with a beam intensity of 3.6×10^8pps (particle per second). This monitor can also be used as an intensity monitor in the range of 10^4~10^9pps.

1 Introduction

To monitor the spill of a slowly extracted beam from the HIMAC synchrotron, a thin plastic scintillator is used, having thickness of 0.2mm. In the case of a low-energy beam, such as 100MeV/u, the effect of multiple scattering is so large that the efficiency of the transport line deteriorates with a large beam size, and the large beam size at the experimental target point becomes unacceptably large. On the other hand, the scintillator becomes brown in a short time, making the output signal small. When the beam center is moved and passes the new point where damage to the scintillator is small, the output signal becomes large. This causes confusion in machine operation, because a larger output signal arises with the same beam intensity. To suppress the effect of coloring, we have to change the scintillator frequently. To improve these problems, we have developed a new beam monitor. In this monitor the following features are required: (1)small multiple scattering, even with a low-energy beam.; (2) fast response to measure a ripple frequency of 1.2kHz; (3) a monitor signal which does not depend on the beam position. To satisfy these requirements, the combination of a thin aluminum foil and an electron multiplier is adopted, where secondary electrons emitted from the foil are collected and multiplied by an electron multiplier. If the gain deterioration of the electron multiplier is sufficiently small, and the beam-position dependence of the output signal is also sufficiently small; we wish to use it as a beam-intensity monitor. In the following, the design consideration, construction, and beam-test results are reported.

2. Design consideration

2.1 Effect of multiple scattering

An approximate formula for the mean square angle (θ^2) of multiple scattering, derived by Rossi and Greisen [1], is as follows:

$$\theta^2 = Z^2 (Es/pc\beta)^2 \ t/X_0, \qquad (1)$$

where Es=15MeV and t is the thickness of the scatterer, X_0 is the radiation length of the scatterer in gms.cm^{-2}, and Z is the charge number; p (MeV/c) and cβ are the momentum and velocity of the scattered particles. The calculated value of θ is the projected angle. The calculated scattering angles with the above formula are shown in Fig.1. While at 400MeV/u θ is about 2.5×10^{-4}rad for a 0.2mm scintillator, it is 8.5×10^{-4}rad for a 100MeV/u carbon beam; the disturbance by this scattering is large. This large emittance growth cause a beam loss in the transport line. To suppress this scattering, an aluminum foil having a thickness of 2μm is used in the secondary-electron monitor. Without any special treatment, a thickness of 2μm is minimum with a surface area of 10×10cm^2 in the case of aluminum foil. As shown in the Fig.1, the scattering angle with 2μm aluminum foil is small even for a low-energy beam.

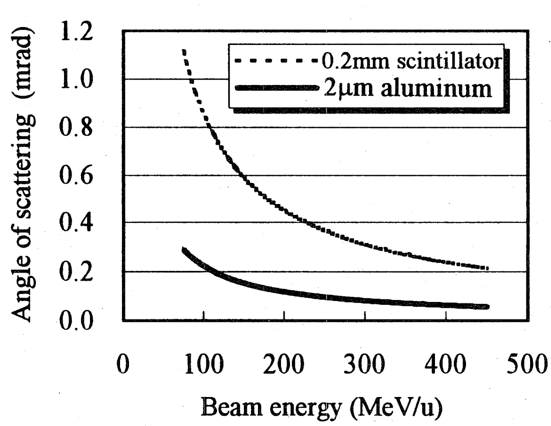


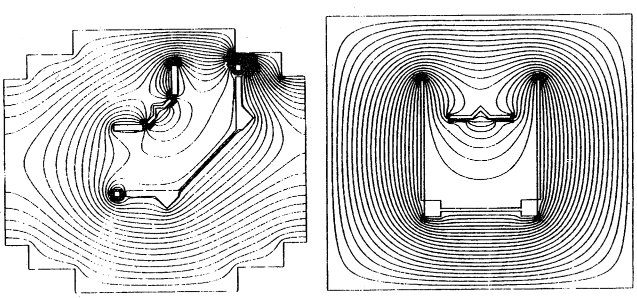
Fig.1 Effect of multiple scattering.

2.2 Yield of secondary electrons

The yield of secondary electrons from aluminum foil was measured by Sudou et al. [2] with carbon and neon beams; their measured values are proportional to the LET (Linear Energy Transfer). Also, the ratio of the electron emission is from 0.4 to 1 with a carbon beam in the energy range between 100 and 400MeV/u. Since the required beam intensity for therapy is 3×10^8pps, the yield of emitted electrons is more than 10^8pps; at a gain of 10^6 it corresponds a current of ~10nC/ms. This would suffice to monitor the ripple component of the beam through the current ripple in the power supply. The secondary-emission is a surface phenomenon. Therefore, the ratio of electron emission is independent of the foil thickness.

3. Structure of the monitor and experimental set-up

The electron multiplier of the ceratron[3] is compact and simple, which is made of a ceramic tube, although the diameter of the sensitive aperture is as small as 6mmϕ. To overcome this shortage, the secondary electrons emitted from the aluminum foil must be collected sufficiently in the small sensitive area of the electron multiplier. To make the desired electric field between the aluminum foil and the electron multiplier, we have arranged additional electrodes. The calculated electric fields with added electrodes are shown in Fig.2.



(a) (b)

Fig.2 Equipotential line calculated by Poisson code.
(a)vertical (b)horizontal

A schematic view of the experimental set-up is shown in Fig.3. There are two H.V. power supplies: one determines the gain of the electron multiplier; the other determines the electric field to collect the secondary electrons. The former power supply is earthed at the positive terminal, which allows the anode-electrode to be set to the ground level of the DC signal. The yield of secondary electrons is too small to be directly observed with the commonly used oscilloscope. The secondary electrons are amplified with an electron multiplier having a maximum gain of 10^6. In choosing the electron multiplier, we adopted a high output current (10μA) type of Murata (EME-2061C). This output signal is further amplified with a current amplifier whose gain is 10^6V/A with a bandwidth of DC to 20kHz (NF LI-76), which amplifies the signal to the maximum output voltage of 10V. The electron multiplier requires a good vacuum of better than 5×10^{-5}torr. The actual vacuum pressure in the chamber was 1×10^{-6} torr.

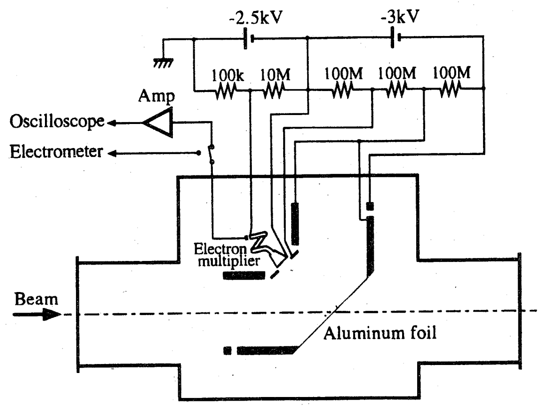


Fig.3 Schematic of the experimental set-up.

4. Test and result

4.1 Beam ripple measurement

The measured signal with a C^{6+} beam, whose intensity is 3.6×10^8pps, is shown in Fig.4. The beam ripple can be clearly observed up to a frequency of 777Hz. This ripple frequency came from the RF-KO [4] process, where the knock-out frequency is modulated with a repetition rate of 777Hz.

4.2 Charge measurement

The output charge from the electron multiplier was measured with an electrometer (Keithley model 610C), directly. In this measurement the beam intensity is monitored with a parallel-plate ionization chamber, which is installed in the beam transport line. By varying the beam intensity widely, measurements can be performed with two ion species of helium and carbon, as shown in Fig.5. In case of carbon beam the output charge is larger than the value of helium by a factor of 5, and is smaller than the calculated value [2] of 9. This tendency is also seen in another paper[2]. The relation between the measured output charge and the beam intensity of carbon is given as follows:

$$Q_{output} = 9^{-14} X_{intensity}{}^{0.89}, \qquad (2)$$

where Q_{output} is the output charge and $X_{intensity}$ is the beam intensity. Though we can estimate the beam intensity from the measured output charge, the obtained relation was deviated from linear dependence on $X_{intensity}$. This is attributed to the reduced gain of the electron multiplier with a high load current in the electron multiplier. Under a beam intensity of ~10^7pps, there is no effect of gain reduction with the load current. To prevent this intensity dependence of the gain, we should use a smaller value of the divider resister than 10MΩ, that is parallel to the electron multiplier in Fig.3. The dark current was 8×10^{-13}C/spill; we use this small value so as to be sure to monitor a beam intensity as low as 10^4pps.

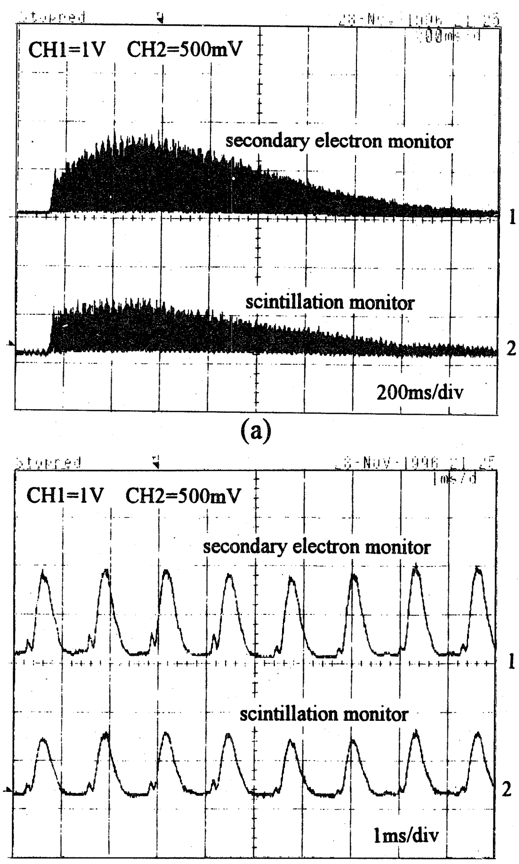


Fig.4 Measured beam ripple. The upper trace is from the secondary-electron monitor. The lower trace is from the scintillation monitor, the beam is C^{6+}, the energy is 290MeV/u, and the intensity is 3.6×10^8pps. The applied voltage of electron multiplier is -1.7kV. (a) 200ms/div (b) 1ms/div.

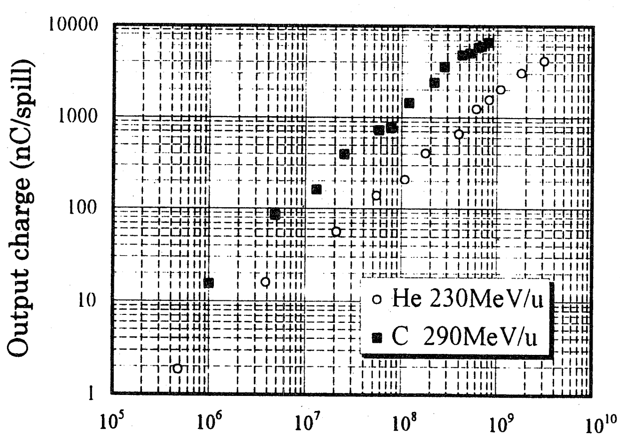


Fig.5 Relation between the output charge and the beam intensity. The foil thickness is 2μm for C and 3μm for He.

4.3 Dependence on the beam position

The output charge was measured as a function of the beam position. As shown in Fig.6, the dependence on the horizontal beam position was small, the uniformity of output charge was within ±2%, and the dependence on the vertical beam position was not very small. This dependence on the vertical beam position comes from the insufficient focusing nature of the vertical electric field. The vertical dependence should be improved to use this as a beam-intensity monitor.

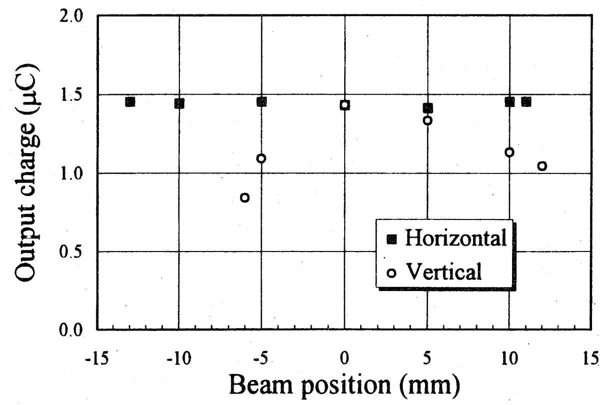


Fig.6 Dependence on the beam position of the output charge.

5. Summary

The ripple of a beam extracted slowly from the synchrotron was measured in the case of a C^{6+} beam with an intensity of 3×10^8pps. Using an aluminum foil with a thickness of 2μm, the effect of multiple scattering could be suppressed to a small value. The beam intensity could be monitored even at a low beam intensity of 10^4pps with this device.

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[3] ceratron is a registered trademark of Murata Manufacturing Co., Ltd.
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