A Non-destructive Beam Profile Monitor Utilizing Charge-division Method at HIMAC

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Abstract

A residual gas ionization beam profile monitor employing a tandem-type MCPs and resistive anode encoder (RAE) has been developed. The monitor works by a method of charge-division to analysis a spatial position. The monitor can measure the transverse density distribution of circulating beam in the synchrotron. The spatial resolution has been achieved less than 0.3 mm represent by r.m.s. beam size of σ for horizontal monitor. The resolution is mainly restricted by noise level entrance to the detector system. A uniformity of the electric field in the work area was carefully designed with the aid of 3D-field simulation code. The monitor has been successfully used for studies of electron cooling as well as studies of beam dynamics under normal-mode operation in the HIMAC synchrotron.

1. Introduction

As a part of the development programs at HIMAC[1], an electron cooler [2] has been constructed and installed in the synchrotron to study transverse cooling mechanisms during the cooling process. In connection with the electron cooler, a non-destructive beam monitor has been required to measure a very narrow beam size accurately. A useful technique for non-destructive beam diagnostics is to utilize the ionization in the residual gas by the circulating beam. This type monitor has been successfully used at many accelerator facilities for a heavy-ion synchrotron and storage ring [3,4].

Previously we had studied the technical realization of this type of monitor with a prototype monitor: RGPM[5], and some characteristics such as sensitivity, reliability and electric field properties were discussed. Although the RGPM had been successfully used to the preliminary test of the electron cooling studies, it has insufficient measurement resolution due to utilizing the multi-strips anode for the detector.

In order to measure such the narrow beam profile a resistive anode position detector has been utilized to a new monitor, and applied the method of charge-division for the position analysis. The method enables one to predict the direction of our object.

In this paper the design and construction, reliability of the monitor and some measurement results of profiles for the cooling beam are described.

2. Design

2.1 Principle of monitor operation

Residual gas ions created by the collision between beam and residual gas are accelerated to a detector in the uniform electric field. In usually the detector system is consisted of micro-channel plates (MCP) and resistive anode encoder (RAE). If the charge (Q) is injected on the RAE which is divided to Q_A and Q_B, and then diffuse to the each side of the RAE, so that the position x coordinate along the detector length of L is measured by

$$x = L\frac{Q_B}{Q_A + Q_B} \equiv L\frac{V_B}{V_A + V_B}, \tag{1}$$

where V_A, V_B are output voltages from charge-sensitive pre-amplifiers. This is the method of charge division and is commonly used for analysis a spatial position of an incident particle with forms a single-event counting. Fig. 1 shows a schematic diagram of the resistive charge division method.

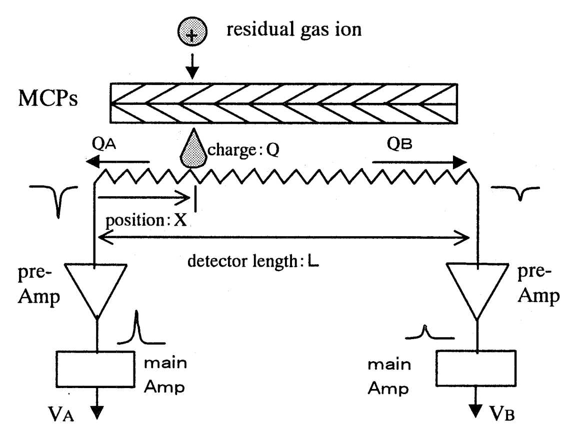

Figure 1. Simplified for position measurements using the charge-division method.

2.2 Layout of monitor

The monitor system is comprised of two monitor units and accompanying correction units for the transverse horizontal and vertical direction, respectively. The correction units act to correct small deflection of the beam orbit kicked by the electric field produced in the monitor units. In the present design the cross-sectional work area of the monitor is designed by 180 mm× 75 mm, which sufficiently covers the maximum beam width at the injection as 120 mm and 60 mm for the horizontal and vertical direction.

The electric field is applied perpendicular to the beam axis, which accelerate the positive residual gas ions created by the beam toward the detector system. The field are produced by two parallel electrodes placed on both sides of the beam pass, and a set of 2-arrays of equally spaced 5-stair electrodes, where the applied field strength are about 112 V/mm and 68 V/mm for horizontal and vertical. The length of the electrodes is 160 mm and 180 mm for horizontal and vertical measured along the beam direction, respectively. In Fig. 2 photo of the horizontal monitor unit is shown.

One of the problems with this monitor assembly is to minimize electric field interaction between field of horizontal and vertical due to its non-symmetrical electric field direction. To minimize the field interaction the components are assembled one by one thing like that V-monitor, V-correction, H-correction and H-monitor along with the beam direction, and are separated about 250 mm for each other. Resulting, the electric field distortion caused by the field interaction between those neighboring electrodes can be negligibly small.

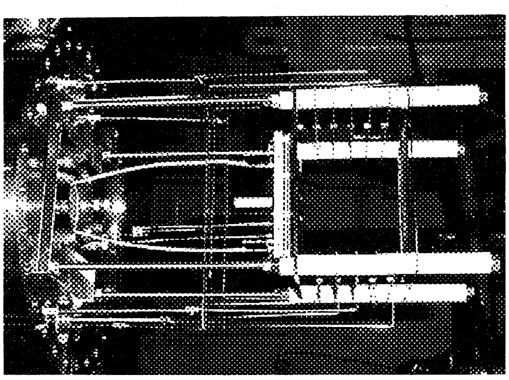

Figure 2. Photo of the horizontal monitor unit.

2.3 *Electric Field property*

It is essential to produce flat equi-potentials distributed in the work area because the reliability of the observation profiles depends strongly on the field distortion. In the previous paper [5] we discussed the electric field property for this type of monitor and extracted some of the technical realization to create a uniform equipotential distributed in the work area with aid of the 3-D field simulator. Resulting, the longer field-shaping electrodes (LF) and the larger space between the electrodes and chamber wall (LS) are better to create more uniform equipotential in the region of interest. In addition, it would be necessary to adjust the divided voltages applied to the electrodes for the reason to compensate any unsymmetrical leakage fluxes.

Based on those studies the electric field of the new monitor was carefully designed with aid of the 3-D field simulator. The simulation results are shown in Table 1. The quantities of the displacement $\delta\zeta$ are roughly calculated by simple relation of $\delta\zeta = E_\perp / E \times \delta l$, where $E_\perp$ is transverse electric field strength, E is the field of parallel to the ion drift and δl is the ion drift length for the horizontal and vertical monitor of 45 mm and 90 mm, respectively. As can be seen from the results the lateral displacements are estimated negligibly small.

Table 1. Characteristic of electric field in the work area

	Horizontal			Vertical		
ζ [mm]	± 2	± 5	± 10	± 2	± 5	± 10
$E_\perp$[V/mm]	0.06	0.12	0.22	0.06	0.17	0.37
$\delta\zeta$ [mm]	0.02	0.04	0.08	0.08	0.23	0.49

2.4 *Readout Circuit*

The RAE-detector consists of a resistive sheet having the resistance of ≅ 7 kΩ at the opposite end, and a stray capacitance having 10 ~ 15 pF mainly formed by the surface of the last MCP and the RAE. Since the RAE is designed to use of charge-division method, the readout circuit is constructed to adopt the method by using suitable NIM modules. The circuit mainly consists of 3-parts as following. 1) A set of amplifiers: charge integration (PA) and shaping to a bipolar signal (MA). 2) Assembly of gate generators to make a coincidence of the single event signal pulses including timing SCA (cross over mode). 3) Computing the event location by an analog circuits (SUM and PSD modules), and provide a shaped pulse to a MCA. Fig. 3 shows a block diagram of the readout system. The maximum count-rate is less than 10 kcps due to restrict by the limit of shaping time of PA.

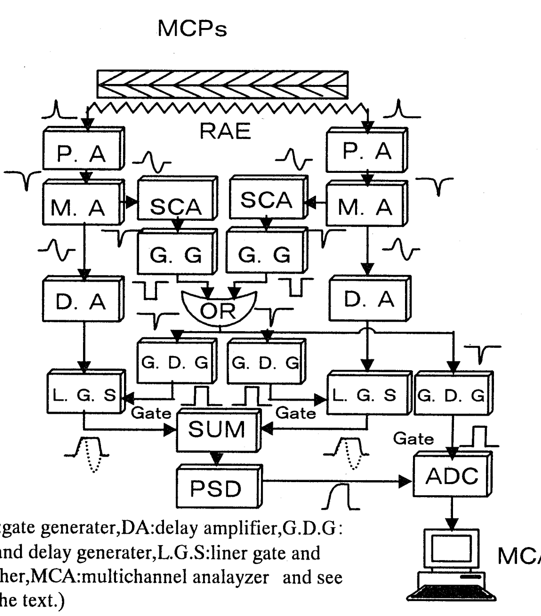

Figure 3. Block diagram of the readout electronics for the Charge-division method.

3. Reliability of monitor

The measurement errors are mainly caused by; a) the electric field produced by the circulating beam, b) the thermal motion of the residual gas molecules and c) the noise level of the read-out electronics circuit.

In the case of a high-density and/or a very narrow beam such as cooled beam, the error caused by a) should be taken into consideration because the force due to the radial electric field created by the beam influences to the ion trajectories. The radial electric field strength[4] is represented by

$$E_r = (\lambda q / 2\pi\varepsilon_0 r)\cdot[1 - e^{-(r^2/2\sigma^2)}], \qquad (2)$$

where λq and σ are line charge density and r.m.s. beam size in Gaussian density distribution and r is the distance from the beam center. For an example, $^{40}Ar^{18+}$ of 6MeV/u as the intensity of 1×10^9 ppp circulating in the ring, the radial electric field strength is approximately 0.35 V/mm at σ = 0.5 mm and r = 0.7 mm.

The error caused by b) is calculated by a simple equation [5]. The results of the calculation the lateral displacement represent by r.m.s. size σ_{th} are 0.07 mm and 0.12 mm for the horizontal and vertical respectively, where the electric field strength of 112 V/mm and 68 V/mm, and ion drift length of 45 mm and 90 mm for the horizontal and vertical monitor are applied to the calculation with the kinetic energy of the residual gas ion of 13 meV at room temperature.

In the method of charge-division, the case of c) effects strongly to the resolution of measurement profile, where the noise generated by the power supply of the synchrotron magnets is mixed in the RAE-detector. The resolution of the readout system included the detector unit is able to calibrate by a simple method, that is to use the test pulse generated by suitable signal-generator and inputted to "TEST" terminal of the both pre-amplifiers. In our case the resolution is obtained by σ_n = 0.25 mm for r.m.s. size, where the amplitude of the noise level is less than ± 30 mV and the signal level is about 4 V at output of the main-amplifier (M.A.) in the circumference of the ring operation. On the other hand the resolution is also estimated by using the Eq. (1) with substitute the parameters Va and Vb for Va ± δ Va and Vb ± δ Vb, where Va and Vb are the signal levels, and δ Va and δ Vb are peak level of the random noise, respectively. Resulting, both the measurement and the calculation are almost same.

The position linearity could be checked with a collimated UV-light which irradiation on to the MCP surface at several points. The measured positions were fitted a form of straight line. As the result 8-ch/mm and 21-ch/mm for each horizontal and vertical monitor in 1023-ch resolution of the MCA are obtained.

4. Performance

In the present, main application of the monitor is measurement of the beam profiles for the electron-cooling beam. Fig. 4 shows a consecutive variation of the measured horizontal beam profiles during the cooling process at different times after the injection. The equilibrium beam size of the measured profiles is 0.77 mm, however, which include the irregular lateral displacements σ_{th}, σ_n and σ_e for the displacement by the electric field as described in section 3. At the intensity of about 1×10^7 ppp, the r.m.s. size σ_e is obtained about 0.05 mm by simulation of ion tracking, so that the cooled beam size is calculated less than 0.71 mm.

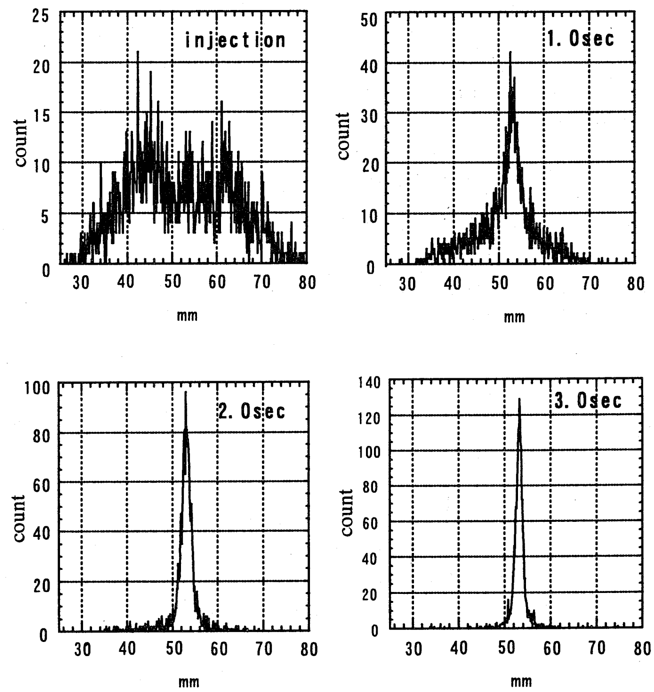

Figure 4. Measured horizontal profiles of the electron-Cooling beam of $^{40}Ar^{18+}$ (6MeV/u) at different times after the injection.

5. Outlook

Presently the RAE-type of non-destructive beam profile monitor utilizing the method of charge-division is described and result of the first application in the cooling beam observation is shown. Now the works are in the analysis concerning the transverse displacement due to the electric field created by the beam for more detail and in the systematic operation of the monitor handling.

6. Acknowledgement

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7. References

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