Test of Non-destructive Beam Profile Monitor at HIMAC

Hiroyuki OGAWA,* Toshihiro HONMA, Yoshinobu SANO,* Koji NODA,
Eiichi TATKADA, Shinji SATO and Hirotsugu OGAWA
Accelerator Engineering Corporation
2-13-1 Konakadai, Inage-ku, Chiba 263-0043 JAPAN
*National Institute of Radiological Sciences
4-9-1 Anagawa, Inage-ku, Chiba 263-8555 JAPAN

Abstract

A prototype non-destructive beam profile monitor employing tandem type MCPs has been installed in the HIMAC Synchrotron. The monitor measured the transverse vertical density distribution of the circulating beam from injection to extraction on the synchrotron operation cycle within a 10msec charge integration time successfully. The technical realization and design studies of the monitor can be applied for the monitor system in the cooler ring project at HIMAC.

1. Introduction

Non-destructive beam profile monitor (NDPM) based on the detection of ionization products of the beam in the residual gas has been tested and further studied at the HIMAC[1] synchrotron. In the previous paper[2],the basic design of the NDPM structure and some results of preliminary performance were already presented. In a series of the tests, this time some unexpected behavior was observed on the measured profiles even if the sufficient signal level was created by the stable beam in the synchrotron. For examples, the observed image profile changed its width and shifted its peak position, simultaneously with changing the collection field strength of the NDPM. That is supposed to be caused by the electric field distortion in the collection field and/or due to ill balanced electric fields between the field of NDPM and the field of correction electrode. Since a cooler ring project utilizing electron-cooling method has been under construction at the HIMAC lower ring, the type of NDPM diagnostic system is required to measure the profile of cooled heavy ion beams accurately.

The aim of the present work is to study the characteristics of the NDPM more precisely, and to design a new monitor system for the cooler ring.

2. Description of NDPM

The NDPM consists of a set of field shaping electrodes, tandem type MCPs which were equipped in a cylindrical stainless-steel vacuum chamber, and signal read out circuits. Fig.1 is a schematic view of the NDPM with a block-diagram of the read out circuits and control system. The collection field is created by the two stacks of copper strips, which enclose an area of 180×75 mm^2 perpendicular to the beam direction, and the length of the strips are 70 mm. A sensitive length is 8mm along the beam direction, which is restricted by the size of MCP. A position sensitive anode consists of 28 strips, having 1.8mm wide and 0.2mm spacing, etched on a printed circuit board. Each anode strip was connected to a charge integrating circuit composition of 3-switch assembly and a capacitor of 1000pF, where the integration time can be changed to control the switching time by the remote operation.

To estimate the number of ions produced by collisions, the energy loss rate was calculated for a single particle of charge ze passing through a material. The calculation was performed by commonly known as the Bethe-Bloch formula[3]. A vacuum pressure is 1×10^{-9} Torr at the location of the detector, which is supposed to be composed of H_2 in residual gas. For a 290 MeV/u carbon particle, the maximum energy transfer in a single collision is calculated to be Wmax=0.73 MeV, and with mean excitation potential of I=19 eV, we get, $-(dE/dx)=1.8\times10^{-14}$ MeV/cm. The number of particles circulating at the flat-top in the synchrotron was assumed 1×10^{9} pps with revolution frequency of 6 MHz, and using a mean energy for ion-pair creation of 33 eV in the effective length of 8 mm, the total Ion-pairs become 2.6×10^{6} pps. Since the MCPs was operated with the gain of 5×10^{4} , the total anode current should be expected about 21 nA.

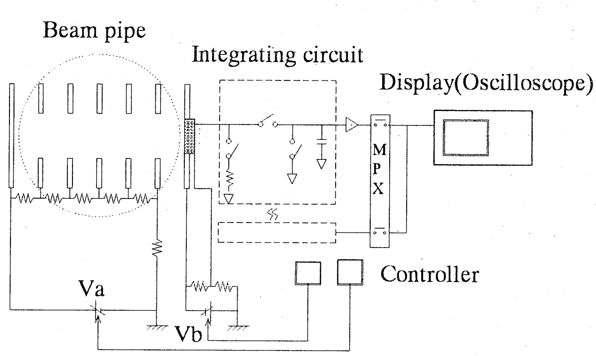

Fig.1 Schematic view of the NDPM with block-diagram of read out circuit

3. Monitor Tests

We have tested the NDPM in the following two situations at HIMAC facility. Firstly the monitor was equipped in the Upper Ring(synchrotron) to observe the beam profiles of the circulating beam, and secondly it was arranged in the HEBT(High Energy Beam Transport) line to survey the accuracy of the observed projections for single pass bunched beam. In both case, the monitor was set in the similar type of cylindrical vacuum chamber.

In the first case, we investigated the basic properties of the NDPM, with circulating carbon beam of 290 MeV/u. Where the vacuum pressure adjacent to the monitor was 1×10^{-9} Torr mainly of H_2, H_2O-vaper, CO+(N_2) and CO_2. Fig.2 shows a quantitative analysis of the residual gas. For the circulating beam intensity of 2.2×10^{9} pps at flat-top in the ring operation, we had a total signal level almost 1.3 V in the projection area displayed on a digital oscilloscope as shown in Fig.3, with the integration time(Ts) of 10 msec. This is in good agreement with the expected values described in the Section 2, taking into account the amplification of tandem type MCPs of 5×10^{4}, conversion ratio of 50nA to 0.25volts in the read out electronic circuit and ionization cross section of the constituents of the residual gas.

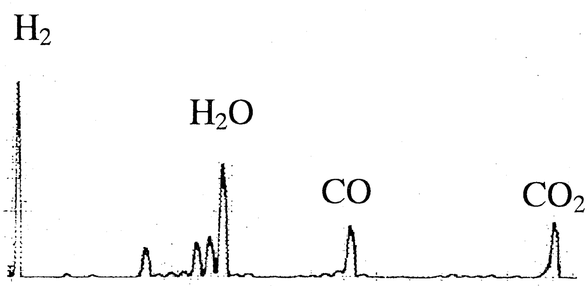

Fig.2. Typical residual gas mass spectrum adjacent of the NDPM in the ring.

The noise level in the NDPM system was less than 20 mV in the environmental condition of measurement, therefore the results of measurement show clearly that, the integration time Ts could be set more short, because of the output signal from the monitor system proportional to the Ts, as can be seen in Fig.4.

The beam profiles at injection, during acceleration and flat-top in the ring operation were also measured with Ts= 10 msec. The typical observed projections are shown in Fig.5. In those tests, there was unexpected behavior on the observed profiles, that the profiles changed its width and shifted its peak position by changing the collection field strength. The effect summarized show in fig.6. This might be due to ill-balanced electric fields between the field of NDPM and the field of correction electrode,

In the second stage, the NDPM was arranged in the HEBT line. The tests were performed to change the vertical beam size by varying the strength of the quadrupole magnets located at 5 m upstream from the NDPM. In this case, the output signal level from the NDPM has considerably low due to the high energy one pass beam of 290 MeV/u, therefore a variable air-leak was equipped to the vacuum chamber. In Fig.7 the relation between signal gains with various vacuum pressure localized at the monitor is shown, and the results are also in agreement with the Bethe-Bloch formula. The measured projections from the NDPM were compared with the profiles from an another profile monitor which has reliability to measure the beam size. The results are shown in Fig.8. In these measurements, however, the different beam sizes were detected on the each monitors, and projections from the NDPM were relatively small compared with the real beam size. This might be caused by the electric field distortion in the collection field.

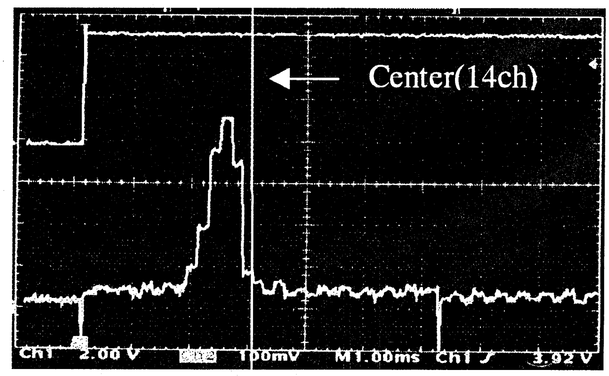

Fig.3 A measured vertical beam projection at flat-top operation cycle of the ring,with C^{6+}:290MeV/u,2.2×10^{9} pps and Ts of 10 msec.

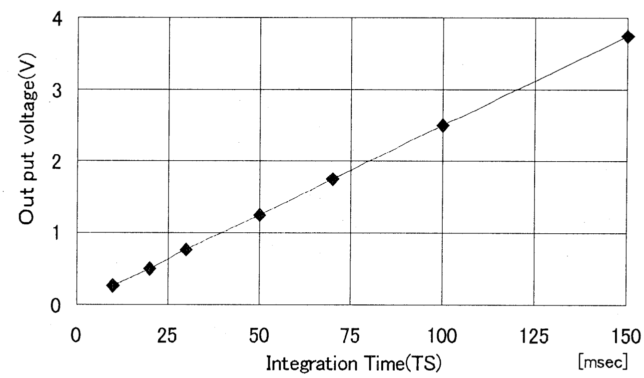

Fig.4. A calibration curve for charge integration time vs. output signal level in the read out circuit.

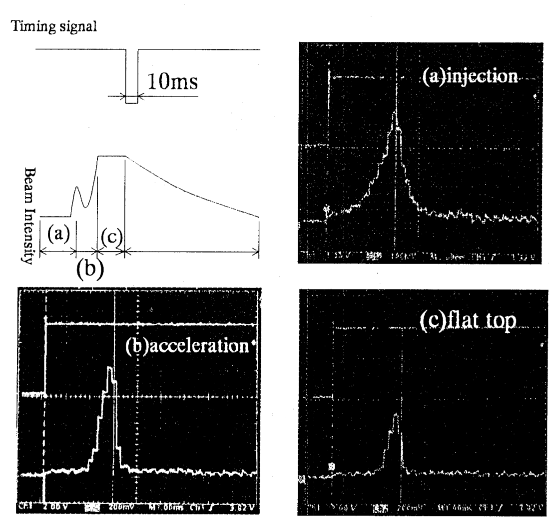

Fig.5 Measured vertical beam projections,(a)injection,(b)during acceleration,(c)flat top in the ring operation cycle, respectively, at Ts=10 msec.

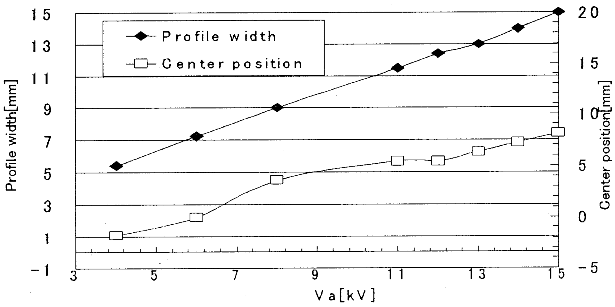

Fig.6 Measurement result of projection change by change of the field strength (applied voltage: Va)

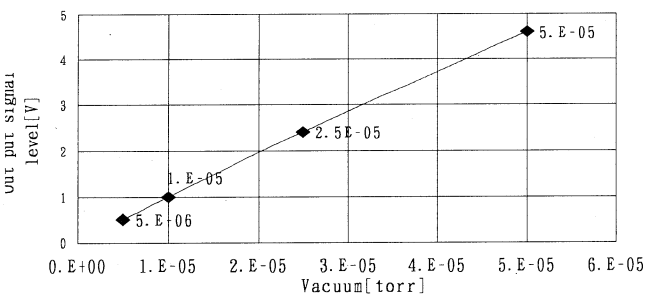

Fig.7 Variable vacuum pressure vs. observed output signal level of the NDPM,with beam of C^{6+}: 290 MeV/u.

4. Electric Field

In the type of this monitor, if the equi-potential lines are given in a way to be flat in the work area, the ions drift straightforwardly to the MCP. In order to investigate the electric field of the NDPM, a 3-dimentional field simulation code[4] has been applied. The first result of the potential distribution at Va=10kV and Vb=-1.5kV(see Fig.1) is shown in Fig.9. From these potentials, the ion trajectories were calculated by using a numerical method[5] with two-dimensional electric fields on the mesh points. The result shows that the drifting ions were affected by a strong focusing action in the collecting field due to the large transverse field component, which was amount of few percents to the field strength toward the detector at the distance of 10 mm from the center.

5. Conclusion

Presently we have tested the non-destructive beam profile monitor (NDPM) employing micro-channel plates with the HIMAC-synchrotron beams, and obtained sufficient signal levels for the particles of 2.2×10^9 pps of C^{6+}:290 MeV/u in the charge integration time of 10 msec. Since the read-out electronics consists of the charge integrating circuits, the total gain can be easily adjusted not only by changing the bias voltage of the MCPs but also by varying the integration time of the circuit. So that we may conclude at this point, the monitor system can be applied to measure the beam profiles in the cooler ring project successfully.

Now the works are in the improvement stage to correct the electric field shape of the existing NDPM for measure the accurate beam profiles, and to design a new monitor for measure a horizontal beam profiles, with 3D field simulations respectively.

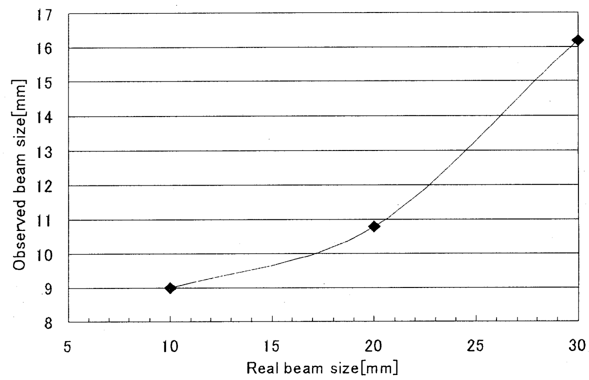

Fig.8 Comparison of real beam sizes and observed projection Measured with the NDPM.

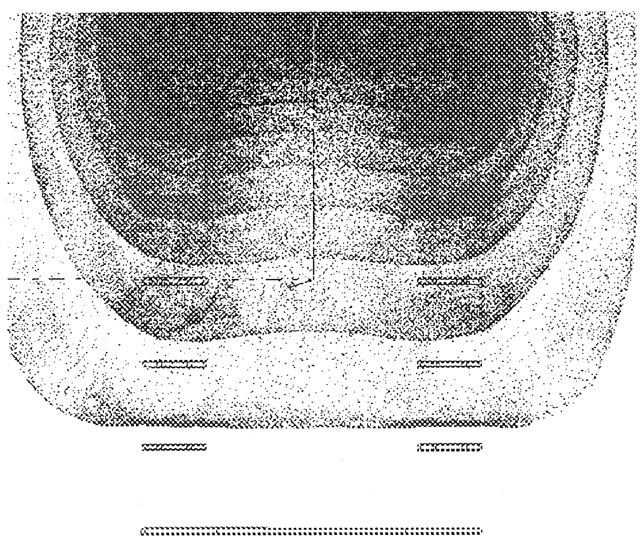

Fig.9 Equi-potential distribution calculated by 3D field simulator for the NDPM, at Va=10kV and Vb=1.5kV

References

[1] E.Takada et al., Proc. 11th Symp. On Accel. Sci. and Tech.,(1997) p347

[2] S.Sato et al., Proc. 10th Symp. On Accel. Sci. and Tech.,(1995) p266.

[3] W.R.Leo, Techniques for Nuclear and particle Physics Experiments, Springer-Verlag, 1987,p24.

[4] "MAXWELL 3D" Field simulator, ver.4.1, Ansoft corporation.

[5] T.Honma, NIRS, "Private note".