PROFILE MEASUREMENT BY THE IONIZATION PROFILE MONITOR WITH 0.2T MAGNET SYSTEM IN J-PARC MR

Kenichirou Satou†, Hironori Kuboki, Takeshi Toyama, J-PARC/KEK, Tokai, Japan

Abstract

A non-destructive Ionization Profile Monitor (IPM) is widely used to measure transverse profile. At J-PARC Main Ring (MR), three IPM systems have been used not only to measure emittances but also to correct injection miss matchings. To measure beam profiles at the injection energy of 3GeV, the high external E field of +50kV/130mm at the maximum is used to guide ionized positive ions to a position sensitive detector; transverse kick force originating from space charge E field of circulating beam is a main error source which deteriorates profile.

The strong B field is also used to compensate the kick force. To measure bunched beam at the flat top energy of 30GeV in the fast extraction mode in good resolution, the strong B field of about 0.2T is needed. One set of magnet system, which consists of a C-type and two H-type magnets, were developed and installed in one IPM system. The IPM chamber was inserted between the 2 poles of the C-type magnet. To make the line integral of B field along the beam axis zero, the H-type magnets have the opposite field polarity to that of the C-type magnet and were installed on both sides of the C-type magnet. Details of the magnet system and its first trials will be presented.

INTRODUCTION

The residual-gas ionization profile monitor (IPM) is one of the most ideal diagnostic tools to measure a transverse profile non-destructively. The most promising way to obtain a clear profile is to measure positive ions using a strong dipole E field (Eext), because this system does not being affected with electron contaminations from electron clouds, a discharge problem on HV feeder. The Eext should be much larger than the strong beam space charge E field (Esc). However, due to the technical limitation of HV being able to apply to an insulator between electrodes, profile distortion will be set in case of high density beams of J-PARC, SNS, LHC, and so on. To reconstruct the original profile from an obtained profile, the numerical calculation methods were developed [1-3], however, before calculation, original profile shape should be assumed.

Another method is to use a uniform magnetic guiding field (Bg), which is parallel to Eext, to collect detached electrons. The Bg converts Esc kick force to gyro-motion along Bg and so called E×B drift along beam axis, where the initial momentum of a detached electron and also a velocity gain from Esc determines radius of the gyro-motion. And this radius determines profile measurement accuracy. However the electron contamination problems are left to be settled. Due to this contamination issue, it is hard to measure the beam tail profile.

Our choice is to use the both methods [4, 5]. We have developed a magnet system for one IPM system (Horizontal type IPM) out of three, and started operation from this June. The Fig. 1 shows photo of horizontal IPM system with new developed magnet system. After describing the details of the magnet, the first measurement results are reported.

Figure 1: Photo of horizontal IPM system installed at address 76 of J-PARC MR.

MAGNET REQUIREMENTS AND PERFORMANCES

The magnet system consists of one C-type main magnet and two H-type correction magnets. The correction magnets are used to cancel the B field integral along the beam axis (BL product) so as not to kick the beam; magnet polarity is opposite

To check the Bg intensity required to measure profiles within 1% accuracy, the profile simulation code IPMsim3D [6, 7] was used. The profile distortions for different Bg settings were checked for a designed maximum beam pulse at the flat top energy of 30GeV. In these calculations, the Gaussian shape was assumed for initial transverse and longitudinal profiles. The expected beam parameters are listed as follows, where 1σ beam emittance for x, and y were set as, 4.4πmm･mrad, and 7.0πmm·mrad, respectively.

- Beam energy:30GeV
- Beam intensity: 4E13 particles per bunch (ppb)
- Transverse beam size: σ_x=2.7mm, σ_y=4.4mm
- Longitudinal beam size: σ_t=10ns

At the IPM centre, the beta function for x and y is β_x=13.1m, β_y=21.6m, respectively, and dispersion function is 0. The initial momentum of an electron was calculated based on the double differential ionization cross section of ref [8]. And Eext was set as -

† kenichirou.satou@j-parc.jp

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30kV/130mm. The obtained profiles in case of Bg=0.05T and 0.2T are shown in Fig. 2. The profiles were fitted with the Gaussian function.

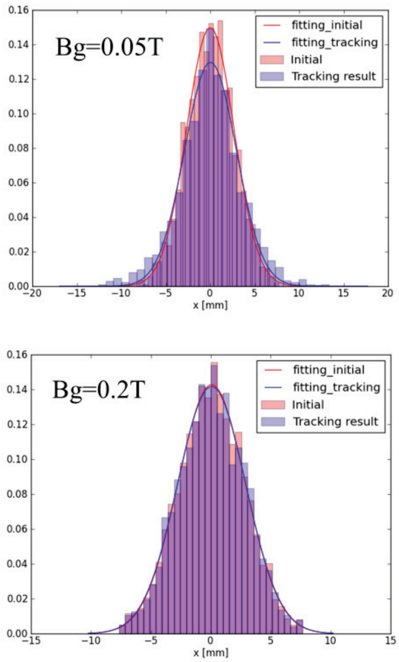

Figure 2: The profiles before (red) and after (blue) the particle tracking calculations. The solid lines are the Gaussian function fitting results.

The ratios of the beam widths obtained from profiles after tracking calculation to the initial ones are shown in Fig. 3. As can be seen from the figure, The Bg>0.2T is needed to measure profile within 1% accuracy.

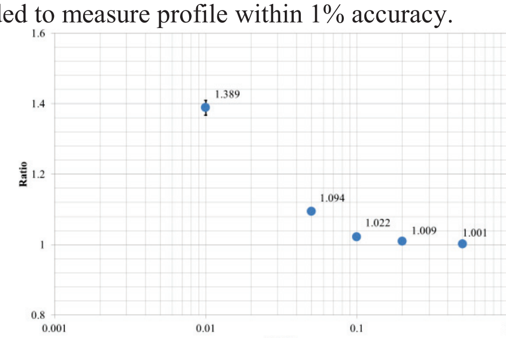

Figure 3: The ratio of calculated beam size to the initial one.

The error field of Bg, the z component Bg_z, makes profile distortion because of the presence of horizontal kick force, Esc_y × Bg_z. The 1% Bg_z/Bg_y makes position shift by at the most 200um and this value can be negligibly small when compared to the horizontal beam size of 2.7mm. The estimated beam size change is only 0.3%.

The design specifications are as follows,

- C-type
    - Pole gap[mm]: 220
    - Maximum Bg[T]: 0.25
    - Effective area[mm]:x=-45~45, y=-40~40, z=-20~20
    - Error fields: Bg_x/Bg_y, Bg_z/Bg_y<1%
    - Flatness of Bg_y: <5%
    - Cooling: Water
- H-type
    - Pole gap[mm]: 150
    - Maximum Bg[T]: 0.13
    - Effective area[mm]:x=-45~45, y=-40~40, z=-20~20
    - Error fields: Bg_x/Bg_y, Bg_z/Bg_y<1%
    - Flatness of Bg_y: <5%
    - Cooling: Air

Figure 4: The C-type magnet pole shape.

The pole shape was determined so as to meet the requirements of error fields and flatness through iterative simulations using the code OPERA-3D [9]. The Fig. 4 shows C-type magnet pole shape. Results of field measurements along the beam axis at a test bench are shown in Fig. 5 and Fig. 6. The error fields were at the most 0.4% and flatness was 1% as shown in Fig. 5, however a part of the errors were caused by the miss-alignment of the magnets. The output field linearity to the input current was checked and shown in Fig. 6. As can be seen from the figure, although the maximum field reaches to 0.29T at 60A in case of C-type magnet, it shows nonlinearity above 0.2T at 40A. As for the H-type magnet, the maximum field was 0.16T at 35A and it shows good linearity for whole range.

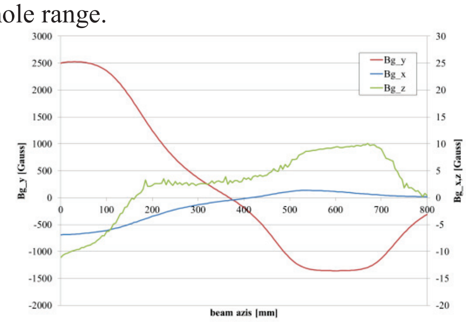

Figure 5: The magnetic fields along beam axis, from the C-type magnet centre to the H-type magnet.

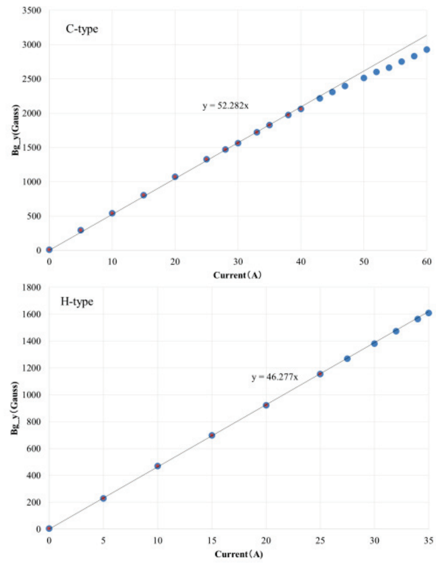

Figure 6: Output fields linearity to the input current.

INTENSITY BALANCE TUNING OF THE MAGNET SYSTEM

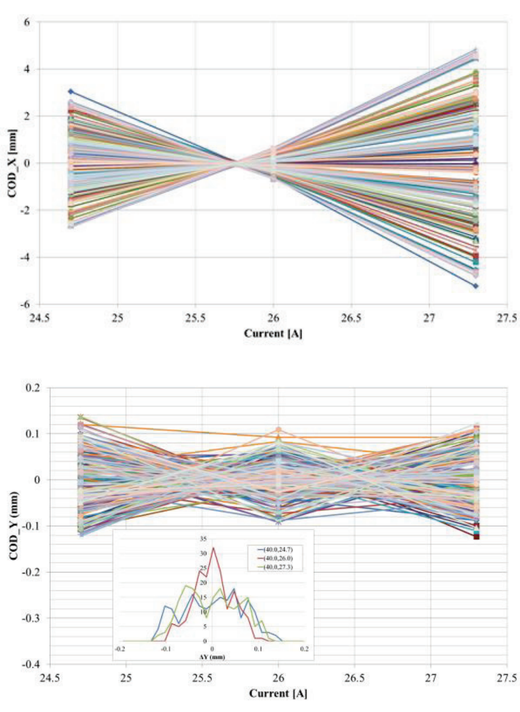

Figure 7: The COD changes for x (COD_x) and y (COD_y) measured with 186 BPMs. The horizontal axis means H-type magnet's current settings which is common for both H-type magnets, where the current setting for C-type magnet was 40A. The histograms of COD_y at different current settings are also shown.

The magnetic field intensity balance between C type and H-type magnets was checked. The residual BL product makes dipole kick and the dipole kick makes the Closed Orbit Distortion (COD). The ratio of the field intensities of the C-type and the H-type magnet, that is the input current setting, should be tuned so as not to show clear COD changes, for example, larger than the typical position resolution of the Beam Position Monitor (BPM) system of about 100μm. We have checked position changes measured by using 186 BPMs after the current settings of (40.0, 24.7), (40.0, 26.0), (40.0, 27.3), where the first element means current setting of C-type magnet and the second element means that of both two H-type magnets in unit of ampere.

The CODs measured at all BPMs are shown in Fig. 7. The cross points showing COD_x = 0mm suggest that the current setting of (40.0, 25.7) is appeared to be the balanced setting. We have also checked the vertical CODs and these does not shows clear position deviations, however the histograms of the (40.0, 26.0) setting shows somewhat smaller width than that of the others. Since the magnet alignment criterion was less than 1mrad, so we expect that the alignment error of the H-type magnet induces small vertical kick and thus CODs, which are less than 100μm.

PROFILE MEASUREMENTS

The first trial of profile measurements were made with the Bg=0.2T and the different HV settings of 4.0kV, 10.0kV, 20.0kV, and 30.0kV. The 2 stage type MCP with 32ch multi-strip anodes has been used as a signal multiplication and charge pick-up device. The width of each strip is 2.5mm. Turn-by-turn beam profiles measured from the beam injection are shown in Fig. 8, where the beam energy and intensity was 3GeV and 5E12 ppb, respectively, and only 1 bunch beam was injected. The beam conditions for the cases 10.0kV and 30.0kV were different from the others; the dipole oscillation was remained due to insufficient injection tunings. Note that the outermost two signals out of 32chs in total, the signals at 38.75mm and -38.75mm, do not work at present due to a failure of front end signal amplifiers.

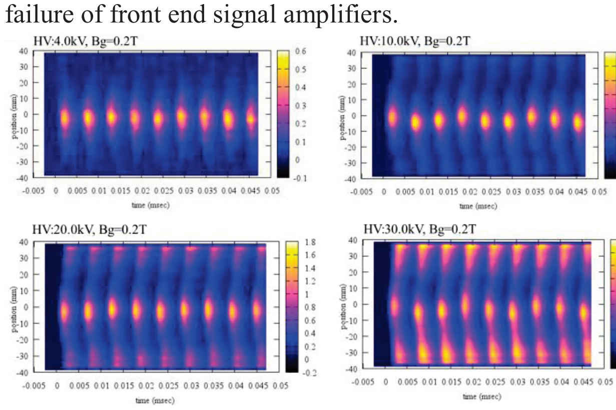

Figure 8: The contour maps of beam profiles with Bg=0.2T and different HV settings, 4.0kV, 10kV, 20kV, and 30kV.

As can be seen in the figure, the electron contaminations appeared on both sides of the MCP detector was increasing with increasing the HV. The ratio of signal intensity of contaminations to real beam signals, which is the ratio of averaged voltage at x=-36.2mm to averaged voltage at the centre, is shown in Fig. 9.

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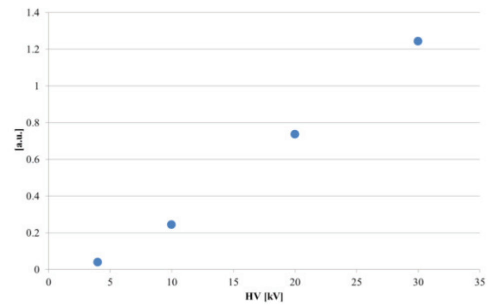

Figure 9: The ratio of electron contaminations to the real beam signals.

DISCUSSIONS

The electron contamination has different and unique profile as shown in Fig. 8 and also different time structure as shown in Fig. 10. The output signal from the anode at x=-36.2mm whose main contribution is likely coming from the electron contamination is compared with the signal from the anode at centre whose main contribution is likely coming from a real beam signal. The beam signal in case of positive ion collection mode without Bg is also shown.

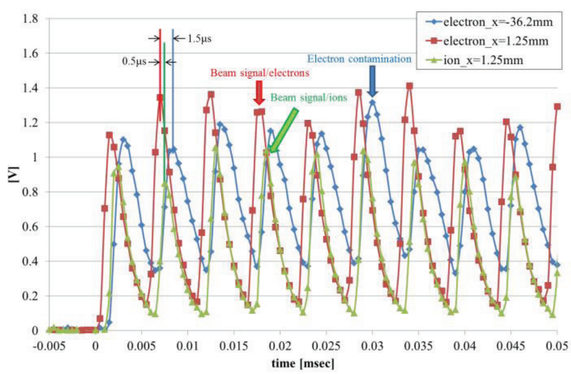

Figure 10: Signals from charge pick-up anodes at -36.2mm and 1.25mm in case of electron collection mode with Bg=0.2T (HV=20kV), and also signal from centre anode in case of ion collection mode without Bg (HV=30kV).

The time difference between a real beam signal of electrons and ions is about 500ns. This time difference is the result of the time of flight (TOF) to the MCP detector, a few ns in case of electrons and a few hundred ns for ions. The electron contamination shows somewhat broad structure and likely arrived on the detector surface at about 1.5μs after beam passage.

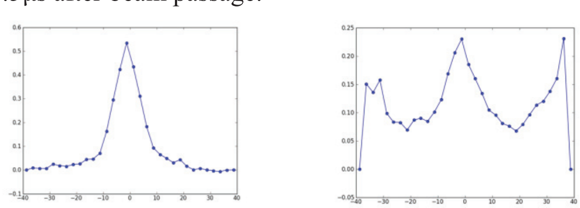

Figure 11: The profiles at 1μs and 5.5μs after beam injection in case of HV=10.0kV setting.

The source of the electron contamination is now unknown and under investigation though, by selecting the timing and minimizing the HV as small as possible, a clear beam profile can be obtained. The Fig. 11 shows profiles at 1μs and 5.5μs after beam injection. However this method cannot be applicable to the full bunch (8 bunches) injection scheme because of the time structure of a bunch train.

There are two candidates for the contamination sources. One is a secondary electrons induced by the ion collisions. At the same time of electron collection with Bg, the same number of ions will accelerate opposite direction and finally collide with electrodes faced MCP detector surface. The noble ion trap method was developed to suppress the ion collisions completely and applied for the new IPM system of CERN-PS [10]. However a signal from this electron would have same time structure of ion collection mode because the TOF of electrons from the surface is negligibly small compared with the TOF of ions to the collision point.

The other candidate is electrons generated outside the effective area of the IPM where uniform fields of Eext and Bg are applied. The tracking simulations were made only for electrons generated near the centre of IPM chamber. The ionization process, electron cloud generation, and discharge problem between electrodes would be sources of the electron generation. To study the electron contamination issue, the IPMsim3D code will be modified so as to calculate electron trajectory traveling through the fringe fields of Eext and Bg together with Esc.

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