BEAM PROFILE MEASUREMENT USING FLYING WIRE MONITORS AT THE J-PARC MAIN RING*

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Abstract

Transverse beam profiles have been measured using flying wire monitors at the main ring of the Japan Proton Accelerator Research Complex (J-PARC). The flying wire is a beam profile monitor using a thin carbon fiber as a target. The beam is scanned with the wire target at the maximum speed of 5 m/s. The secondary particles from the beam-wire scattering are detected using a scintillation counter as a function of the wire position. The measurement has revealed a characteristic temporal change of the beam profile during the injection period of 120 ms. The multi-particle tracking simulation program, SCTR, taking account of space charge effects has successfully reproduced the beam profiles.

INTRODUCTION

The main ring (MR) of the Japan Proton Accelerator Research Complex (J-PARC) is a high intensity proton accelerator and delivers the protons for the nuclear and elementary particle physics, such as the neutrino oscillation experiment (T2K). The injection energy is 3 GeV and the extraction energy is 30 GeV. For the user run we have achieved the beam power of 145 kW with 8 bunches of 1.17×10^{13} protons per bunch (ppb). Two bunches of protons are injected in MR from the rapid cycling synchrotron (RCS) through the beam transport line (3-50BT). Two bunches are injected four times in one cycle to fill 8 out of 9 rf buckets in 120 ms. The acceleration starts after 50 ms of the fourth injection.

The beam loss minimization and localization at the collimator are necessary to minimize residual radiation activities in MR and required for the maintenance of the accelerator components. The typical beam loss is 1% during the injection period and 0.7% at the beginning of the acceleration. It is important to understand the beam loss mechanism for further beam power increase.

The transverse beam profile is one of important beam parameters to measure for understanding of the beam loss mechanism. We have installed ion profile monitors (IPM)[1] and flying wire in MR. IPM uses phenomena that the proton beam ionizes the residual gas. Flying wire monitors for horizontal and vertical beam profiles have been installed at the straight section where the beam loss is relatively low, because the beam loss becomes background for the profile measurement. Multi-ribbon profile monitors[2] have been installed at five places in 3-50BT and one in MR. They are being used to measure the injection beam profiles.

FLYING WIRE MONITOR

Flying Wire Monitor uses a carbon fiber of 7 μm in diameter as a target. It is to be scanned across the beam with the maximum speed of 5 m/s. The secondary particles from the beam-wire scattering are detected with a scintillator (Fig.1). The beam profile is then reconstructed from the scintillator response and the wire position measurement. If the wire scanning disturbs the beam, the profile measurement is not precise. The minimum target material and fast wire scanning are then necessary. Flying wire monitors have been used in several proton accelerators. It was also developed in KEK-PS[3] and modified for J-PARC MR[4].

The wire flame is rotated from -150° , which is the standby position, to +150° and comes back to the standby position. The movement is done in 0.2 s. The wire scanning takes about 5 ms for a typical size of the beam. The scintillator signals and the potentiometer output signals for the wire position are digitized with a digitizer RTD720A with a 20 ns sampling for a 20 ms time range. The 1 M sample data are averaged over 10 k sample to make arrays of 100. The data of the potentiometer signal is calculated to make wire position data. Scattered plots are made for the scintillator data as a function of the wire position to make beam profiles. The betatron amplitude function βx is 15.4 m at the position of the horizontal flying wire and βy is 18.5 m at the position of the vertical flying wire.

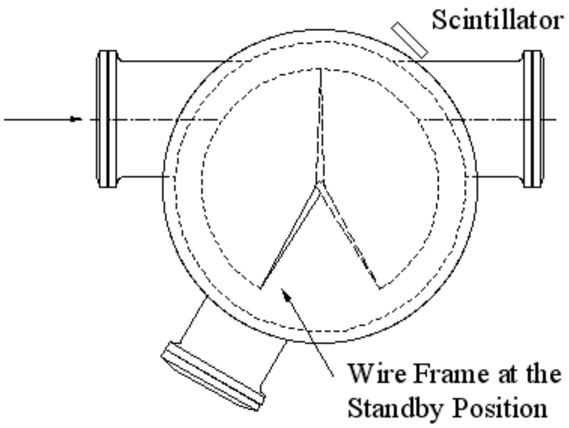

Figure 1: The flying wire monitor.

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BEAM PROFILES AT INJECTION

The profile data have been acquired with changing the trigger by 1 ms step with respect to k1 (the injection timing of the first bunch), because we would like to observe the profiles immediately after the injection. Figure 2 shows the horizontal beam profiles for the beam intensity of 0.6×10^{13} ppb. In order to reconstruct the beam profile immediately after the injection, we should take the profile data with smaller trigger steps such as 0.2 ms and rearrange the data as a function of the timing with respect to the injection timing. The analysis has not been done for this sequence of profiles. We have, however, observed a change at the top of the profile in 10 ms after the injection. The profile peak was observed to be sharper immediately after the injection.

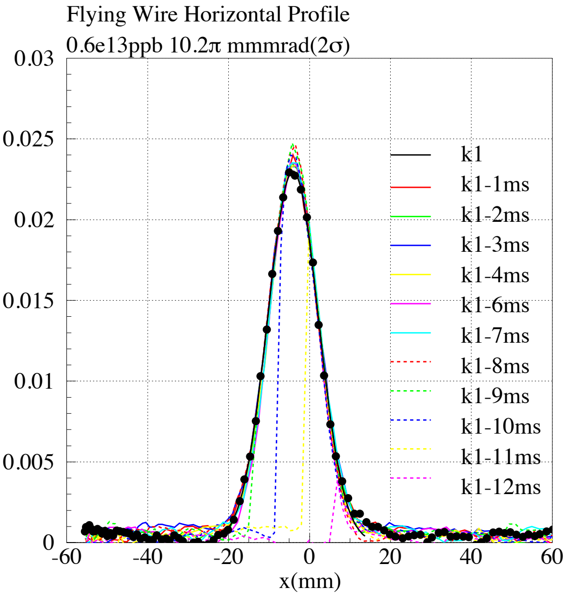

Figure 2: Horizontal beam profiles at the injection for the beam intensity of 0.6×10^{13} ppb.

PROFILE CHANGE DURING THE INJECTION PERIOD

Beam profiles have been measured during the injection period for the beam intensity of 0.95×10^{13} ppb and 1.19×10^{13} ppb. Only horizontal profiles have been acquired for 0.95×10^{13} ppb. Both horizontal and vertical profiles have been acquired for 1.19×10^{13} ppb. Trigger timing was set to k1, k1+20 ms and k1+120 ms to observe the profiles during the injection period.

Figure 3 shows the horizontal profiles for the beam intensity of 0.95×10^{13} ppb. The profile at the k1 timing was observed to be in a Gaussian shape. The 2σ emittance was 17.8π mmmrad. A small change of the profile has been observed at the k1+20 ms timing from the Gaussian shape. The profile change was clear at the k1+120 ms timing. The profile was in a parabola shape. The 100% emittance was 24.4π mmmrad.

Both horizontal and vertical profiles for the beam intensity of 1.19×10^{13} ppb have been observed to have the same change. They were in a Gaussian shape at the k1 timing and in a parabola shape at the k1+120 ms. The beam emittance was larger than that for the beam intensity of 0.95×10^{13} ppb. The horizontal 2σ emittance was 20.1π mmmrad and the vertical emittance was 24.7π mmmrad at the k1 timing. The horizontal 100% emittance was 36π mmmrad and the vertical emittance was 26π mmmrad at the k1+120 ms.

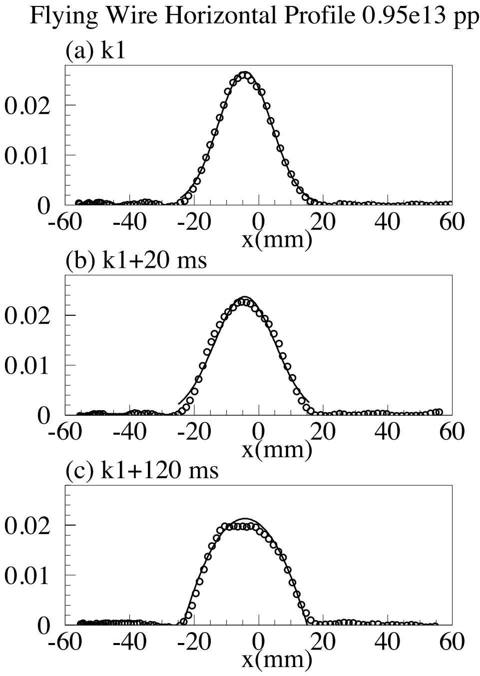

Figure 3: Horizontal beam profiles at the trigger of k1 (a), k1+20 ms (b), k1+120ms (c).

SIMULATION RESULTS

Multi-particle tracking simulations with the space charge effect have been performed to understand the profile change. The simulation code SCTR[5] which uses the particle in cell model for the space charge field calculation has been used. The space charge field was calculated at 1006 elements for the MR circumference od 1567.5 m with a 1 mm grid of 128×128. A typical number of multi-particles was 200,000. The total number of elements was 3755 for such as magnets, drift, rf and space charge elements. Imperfections were implemented for magnet errors, multipoles and alignment errors.

Figure 4 shows the simulation results for the horizontal beam profiles for the beam intensity of 0.95×10^{13} ppb. The initial distribution was set to be the Gaussian distribution that was the observation at the k1 timing. A small change of the profile was seen after 20 ms. The profile change was clear after 120 ms. The profile was in a parabola shape as it was observed with the flying wire. The simulation reproduced the profile change.

To understand the mechanism of the profile change, we have performed the test particle tracking. Ten test particles with 8.1 π ~ 81 π mmmrad were tracked for 1000 turns through the space charge fields. The lattice tune was (22.4, 20.75). The tunes of the test particles are shown in figure 5. The phase space plots are shown in figure 6. The results indicate the linear and 3rd order coupling resonances are the causes of the profile change.

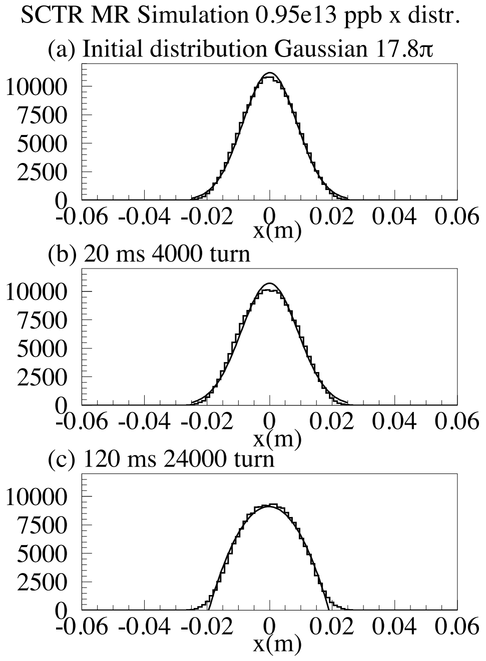

Figure 4: Simulation results for horizontal beam profile for the initial distribution (a), profile after 20 ms (b), profile after 120ms (c).

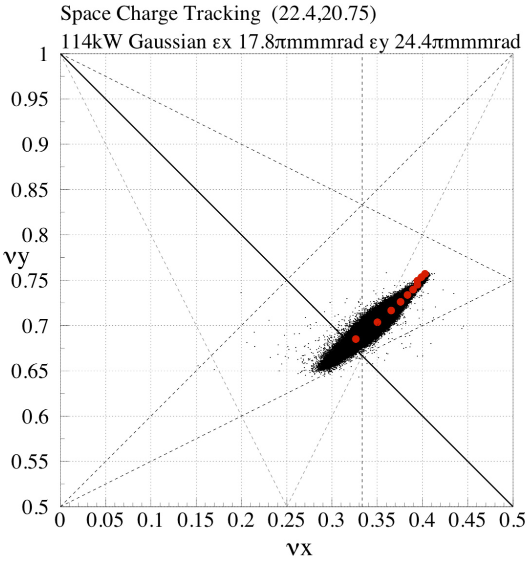

Figure 5: Simulation results for the incoherent tune shift for the beam intensity of 0.95 × 10^{13} ppb. Red dots show the tune of ten test particles.

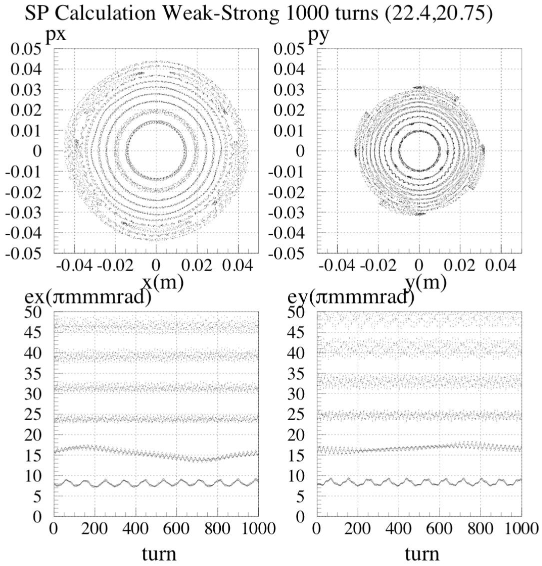

Figure 6: Simulation results for the test particle tracking for the beam intensity of 0.95 × 10^{13} ppb. The phase space plot x-px (top left figure), y-py (top right), ex as a fuction of the turn number (bottom left) and ey as a function of the turn number (bottom right).

SUMMARY

The transverse beam profiles have been measured using the flying wire monitor at the J-PARC MR. A characteristic profile change has been observed during the injection period. The space charge simulation code SCTR reproduced the profile change. The linear and 3rd order coupling resonances were the causes of the profile change.

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