BEAM POSITION MEASUREMENT USING LINAC MICROSTRUCTURE AT THE KEK BOOSTER SYNCHROTRON

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Abstract

The position information of the most recently injected beam from the linac is obtained by picking-up the signal of the harmonic component of the beam, if the bunch structure disappears during one turn due to the momentum spread. The experiment for 201MHz pickup was performed in the KEK booster ring, and is compared with the simulation. The possible application of this method to the 3GeV rapid cycling synchrotron in the Japan Proton Accelerator Research Complex (J-PARC) is also addressed.

1 INTRODUCTION

In the KEK 500MeV booster synchrotron, 40MeV H^- beams from the 201MHz linac are injected by multiturn process during 40 μs or less. The beam dilutes in a longitudinal direction due to the momentum spread as,

$$\Delta T / T = (\alpha - 1/\gamma^2)\Delta P / P , \qquad (1)$$

where, T is the revolution period, α the momentum compaction factor, γ the Lorentz gamma, and P the momentum. The evolution of the bunch structure in the ring is shown in Fig.1, where the micro-bunches are injected every 5 ns with $\Delta P/P$ of ±0.35 % and bunch length of ±35 deg at the linac output. Figure 2 shows the harmonic components of bunches. It is clearly seen that the harmonics fade away very quickly during turns. It is then suggested that, if the beam position monitor (BPM) picks up these harmonics, the position information of the most recently injected beam can be obtained irrespective of the positions of the previously injected beams.

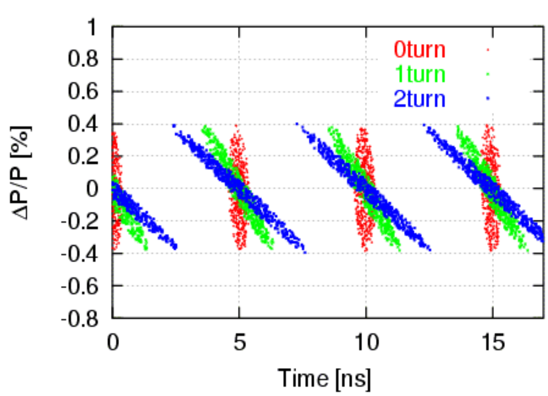

Figure 1: Bunch structures during subsequent turns in the KEK booster ring.

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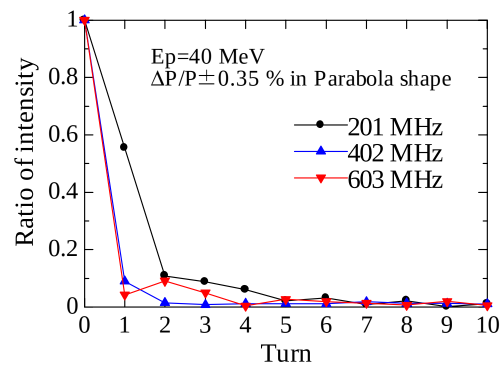

Figure 2: Evolution of each harmonic component during turns. The signal intensity is normalised to 0th-turn value.

2 EXPERIMENTS

2.1 EXPERIMENTAL SETUP

The KEK booster is a rapid cycling synchrotron (RCS) at 20Hz repetition, the circumference of which is 37.7 m and the revolution period at injection about 445 ns. The injection is performed by charge exchange method using a carbon stripping foil. The BPM is an electrostatic type and has 4 electrodes [1], which is located 3.6 m downstream of the stripping foil. The pickup signals are fed into an isolation transformer and transferred through coaxial cables to the central control room. The typical pulse height of the raw signal is several milli-volts. These were inputted to an oscilloscope with a 2GHz sampling rate, and then transferred to a PC where the FFT calculations were performed over each 445ns time range. The harmonics used to calculate the position is 201MHz because the signals of higher harmonics are too small. The conversion to the position from the 201MHz amplitude is given by

$$x = k(R - L)/(R + L), \qquad (2)$$

where R and L is the signal from the right and left electrode, respectively, k the conversion coefficient to position. The k-value of this study is 19.84 mm.

In order to compare the beam positions with and without the presence of the circulating beam, the extraction bump magnet is provided downstream the BPM, which kicks the beam out so as to prevent the further excursion. At the 40MeV beam-transport line, the momentum analyser system is available to observe the momentum distribution of the incoming H^- beam.

2.2 EXPERIMENTAL RESULTS

In order to check the performance of the BPM, the injected beam was kicked by a horizontal steering magnet located at the 40MeV beam-transport line. The beam position versus the steering magnet current is shown in case that the extraction bump is ON. The error bars in the figure indicate the fluctuations in the consecutive five measurements. As expected, linear dependence is obtained.

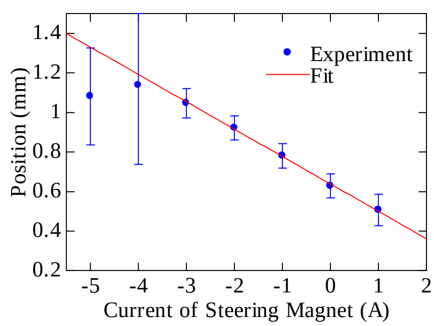

Figure 3: Steering current vs. position response. Line is fitted above the current -3 Amps.

Figure 4 shows the comparison of the signals in the horizontal plane with the extraction bump magnet On and Off. It is clear that the electrode signals and thus the beam positions are different each other, which implies that the 201MHz component survives more than one revolution in the ring.

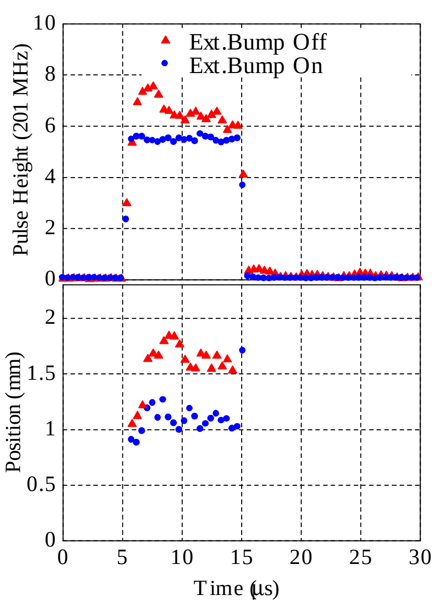

Figure 4: Experimental results of the sum signal of horizontal electrodes (top) and the position (bottom).

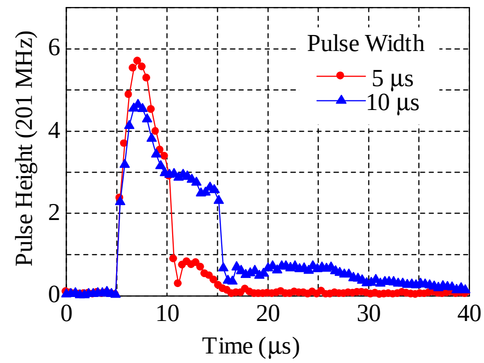

Figure 5: Experimental results of the sum signals with RF Off.

As shown in Fig.5, the bump of 201MHz component appeared after the injection end. Such bumps can be thought as re-bunching in the ring. The data was taken when the RF system of the ring is turned off for simplicity.

3 ANALYSIS

Parameters in the simulation are the central energy, and the shape and width of the momentum spread of the injected beam. Typical momentum distribution is shown in Fig.6. The output of the velocity monitor in the 40 MeV line was used to determine the central energy of the beam. The influence of RF or the space charge effect was not included: space charge effect for one revolution is about 8.8 KeV, which is much smaller than the typical energy spread of the bunch, 274 KeV. In calculation, bunches are injected by multi-turn injection in the same manner as the practical beam injection. The time and the output signals of the BPM are recorded and accumulated. After the end of tracking calculation for all particles, the 201MHz component is picked up by FFT, and then the position information is deduced. Figure 7 shows the calculation result which compares to Fig.4. The initial values for (x, x') were given so as to reproduce the experimental position with the extraction bump On. General trend of the calculation agrees well with the experiment.

Figure 8 shows the calculation which produces the 201MHz bump after the injection end. A square momentum distribution with ±0.3 % spread is assumed although this distribution is slightly different from that in Fig.6: it should be noted that the operating condition of the linac during the course of this experiment was not always stable. The momentum distribution might be changing.

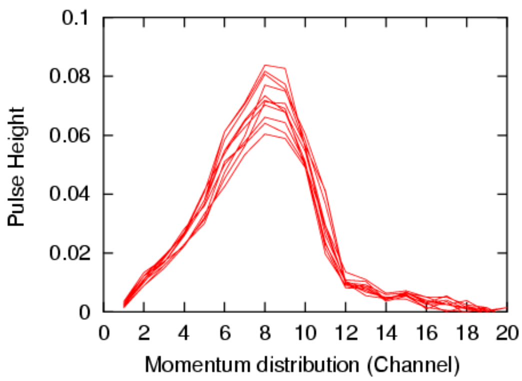

Figure 6: Momentum distributions by the analyser magnet system in the 40MeV line. Each line is obtained in every 0.8 μs. $\Delta P/P$ = 0.0735 % /channel.

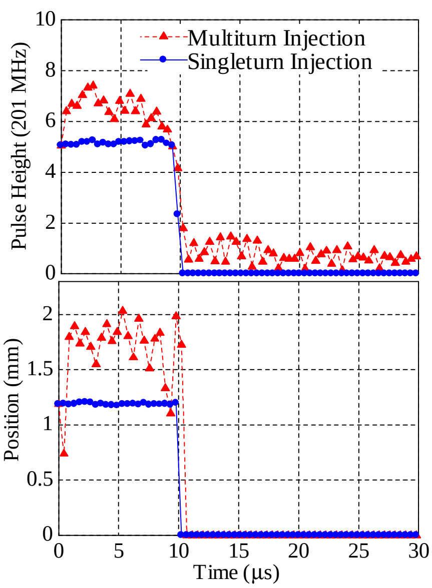

Figure 7: Results of simulation for Fig.4. The data of momentum analyser was used in the simulation.

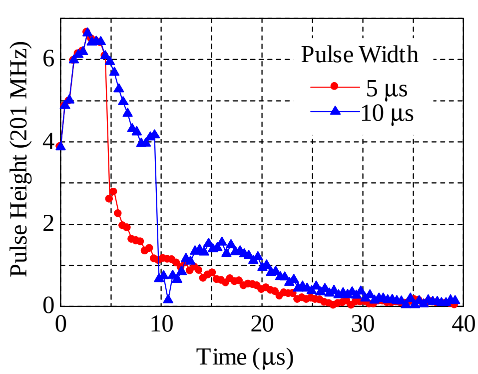

Figure 8: Simulation of re-bunching which compares to the experiments in Fig.5. A square momentum distribution with ±0.3% spread is employed.

4 APPLICATION TO J-PARC

In the 3GeV RCS of the J-PARC, painting injection which forms a uniform density distribution in the real space is planned[2]. In order to precisely control such a process, a realtime monitoring system of the injected beam is foreseen. Parameters of the beam and the RCS are: fundamental frequency of the micro-bunches from the 400MeV linac is 324MHz, the micro-bunch length $\pm$17deg with $\Delta P/P \le 0.1\%$ at the stripping foil, the circumference 348m, and the momentum compaction factor 0.001197. The evolution of each harmonics in the RCS is shown in Fig.9. Since the bunch length at the foil is short, the intensity of the higher harmonics is high enough to be observed. If the BPM's, which are based upon the 3rd harmonics, are distributed in the ring, the phase coordinates of the most recently injected beam can be deduced because almost no 3rd harmonics survives over one turn as can be seen in the figure.

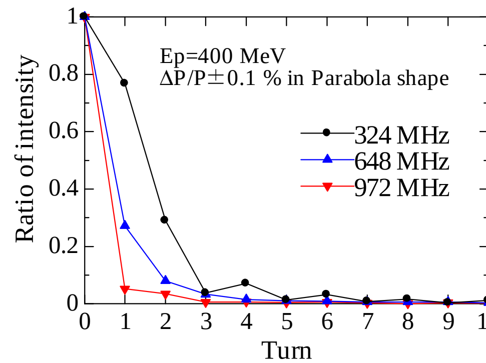

Figure 9: Evolution of each harmonic component in the J-PARC RCS. The signal intensity is normalised to 0th-turn for each harmonic frequency.

5 SUMMARY

The study of the beam position monitor in the KEK booster ring is in progress which observes the fundamental frequency of the linac beam. The agreement between the experiment and the simulation is reasonably well although the simulation showed evolution of the harmonics is quite sensitive to the momentum distribution of the injected beam. The application of this method to the J-PARC 3GeV ring seems promising in order to realtime monitor the painting injection process if the BPM's are based upon the 3rd harmonic component of the 400MeV linac beam.

REFERENCES

[1] H.Someya, D.Arakawa, J.Kishiro and I.Yamane: Proceedings of the meetings ICANS-XIII and ESS PM4, PSI proceedings 95-2, pp.740-744.

[2] I.Sakai et al: this proceeding.