A PULSED QUADRUPOLE MAGNET INJECTION AT THE PF-AR STORAGE RING

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Abstract

Since a beam injection using a pulsed quadrupole magnet (PQM) was achieved at the Photon Factory Advanced Ring (PF-AR) in September 2004, we have continued the beam injection study to accumulate the beam up to a current of 60 mA. We observed that the saturation of the stored beam current in the PQM injection was strongly dependent on a total rf voltage. In order to investigate the dependence, various experiments were carried out. Through the experiments using a turn-by-turn beam position monitor, a beam scraper and a fast gate camera, we found that the dependence was generated by the instabilities coupled with the excitation of the PQM, which formed a long tail of the beam profile and resulted in the beam loss of the stored beam

INTRODUCTION

In order to overcome the strong beam instabilities during the injection with a lower energy at the Photon Factory Advanced Ring (PF-AR), various attempts have been carried out. The main parameters of the PF-AR are listed in Table1. One of the attempts was to realize new injection scheme using a pulsed quadrupole magnet with no local bump [1]. This new scheme seemed to be effective for the beam injection of the PF-AR since the PQM could not generate the coherent dipole oscillations so much. However, we have met much higher barrier than the conventional injection scheme with the dipole kicker magnets.

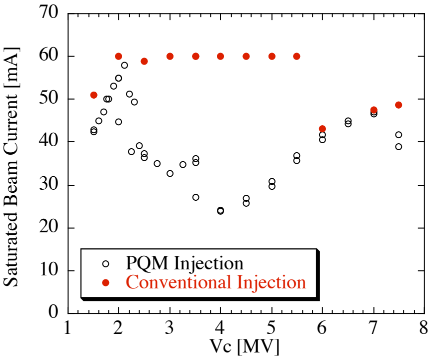

Figure 1: Saturated current of the stored beam as a function of a total rf voltage (Vc). Red circles and black open circles represent the beam currents stored using a conventional injection system with a local bump and new injection system with the PQM, respectively. Because the maximum stored beam current is limited to 60 mA by the PF-AR injection system internally, the plot of the conventional injection has a flat region. The strong dependence on the total rf voltage was observed in the beam injection using the PQM. The injection was carried out at a repetition rate of 12.5 Hz.

Table 1: Main Parameters of the PF-AR.

Beam energy	6.5 GeV
Circumference	377 m
Natural emittance	293 nm·rad
RF Frequency	508.6 MHz
Injection Energy	3.0 GeV
Typical number of bunches	1
Initial Stored Current	60 mA
Beam lifetime (at initial stored cur.)	20 hours

Figure 1 shows the saturated current of the stored beam as a function of a total rf voltage (Vc). The strong dependence was observed for the beam injection using the PQM. While the saturated current reached about 60 mA around the 2 MV, it decreased down to 25 mA around 4 MV. On the other hand, for the conventional injection scheme, the saturated current reached 60 mA in the wide voltage region from 2 to 5.5 MV. The saturation current of the stored beam in this region is quite different between the two injection methods. In order to investigate the source of the difference, we conducted several experiments.

EXPERIMENTS

Measurement of Loss Rate for the Stored Beam

First, we examined what happened in the stored beam when the beam current was saturated during the injection. Figure 2 shows a typical trend of the stored beam during the injection with the PQM at a total rf voltage of 4 MV and a repetition rate of 5 Hz (12.5 Hz in figure 1). Although the injection rate below the stored current of 11 mA was almost constant to be about 0.1 mA/sec, it gradually decreased and reached zero. The beam current was saturated at the stored current of 13mA. Figure 3 shows the beam loss rate with and without the PQM excitation as a function of the stored beam current. The beam loss rate due to the PQM excitation was obtained by measuring the change of the stored beam current for one minute without an injection beam. The excitation frequency of the PQM is 1 Hz. No beam loss was observed without the excitation of the PQM. On the other hand, the beam loss rate with the PQM excitation rapidly increased around the stored beam current over 10 mA. The beam loss rate at the stored current of 13 mA was

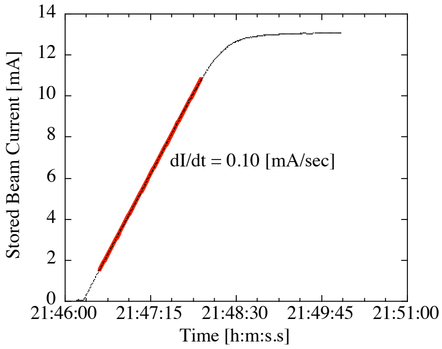

Figure 2: Trend of stored beam current in the beam injection with the PQM. The stored current is saturated around 13 mA with a total rf voltage of 4 MV. The injection rate is calculated to be about 0.10 mA/sec. The injection is carried out at a repetition rate of 5 Hz.

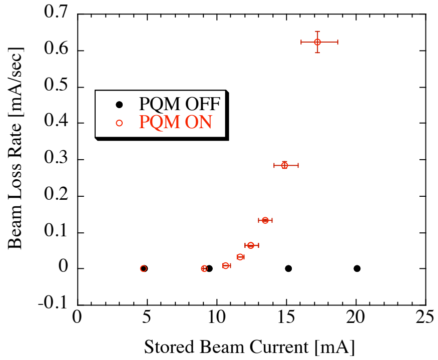

Figure 3: Beam loss rate as a function of the stored beam current. Black closed and red open circles show the rate without the excitation (OFF) and with the excitation (ON) of the PQM, respectively. The measurements were carried out for one minute at a repetition rate of 1 Hz.

calculated to be 0.1 mA/sec and this value was almost equal to the injection rate. The loss of the stored beam due to the excitation of the PQM is the reason why the stored beam is saturated at the stored current of 13 mA.

When the Stored Beam is Lost?

Next, we examined when the stored beam was lost after the excitation of the PQM. We monitored a coherent dipole oscillation and the stored beam current using a turn-by-turn beam position monitor (BPM) with four electrodes. The horizontal dipole oscillation generated by giving a slight offset on the PQM was detected. Figure 4 (a) shows the horizontal beam position as a function of the turn number of the bunch indicating the excitation timing of the PQM corresponds to 1112th turn. Figure 4 (b) represents sum of the signals from four electrodes, which corresponds to the stored beam current. In these figures, data of sixty turns are selected and vertical axes are shown by arbitrary unit. Through the turn-by-turn measurement of the beam current, we found out that most of the beam loss occurred within twenty turns just after the excitation of the PQM. In addition, the growth of the coherent dipole and quadrupole oscillations were not observed until ten thousand turns.

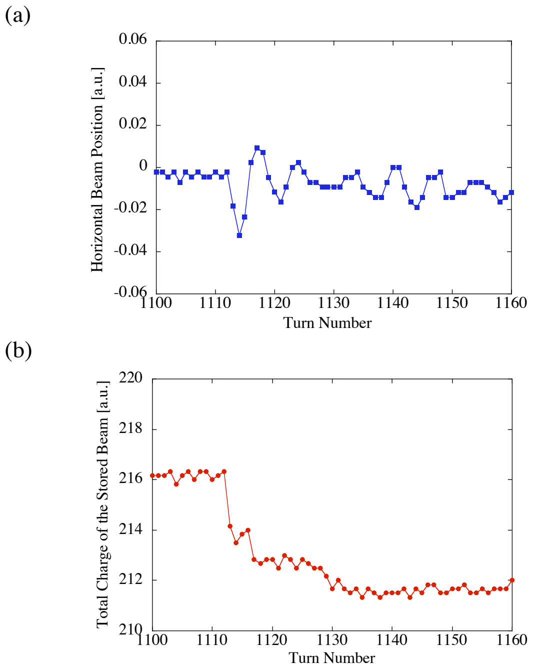

Figure 4: Horizontal position (a) and current (b) of the stored beam as a function of a turn number detected by using turn-by-turn beam position monitor. The excitation timing of the PQM is corresponding to 1112th turn.

Where the Stored Beam is Lost?

From the timing when the beam loss occurred, we guessed that the extension of the beam size was generated by the instabilities having a particular beam current threshold and the beam size was further extended by the excitation of the PQM. As a result, the stored beam might hit a vacuum chamber which limits the ring apertures and then a part of the beam might be eliminated. In addition, the beam loss rate might depend on the extension rate of the beam size and the strong dependence on the total rf voltage might be observed consequently.

In order to prove the guess, we measured the transverse size of the stored beam using a beam scraper with the excitation of the PQM. The beam current of 20 mA was initially stored and then the PQM was exited at a repetition rate of 1 Hz. The beam loss rates were measured as a function of the scraper position from the beam center, which are shown in Figs. 5 and 6. As the total rf voltage, we chose 2 MV and 4 MV between which we observed the clear difference in the saturated stored beam current as shown in figure 1. At 2 MV, the full widths calculated from the beam loss rate were 30 mm and 7 mm in the horizontal and vertical directions, respectively. On the other hand, they were 43 mm and 15 mm at the voltage of 4 MV. The horizontal width at the voltage of 4 MV was about 1.5 times wider than that at the voltage of 2 MV and the vertical width was about twice wide. Moreover, we searched the location where the beam loss occurred using the local bump method. However, we could not identify the location yet.

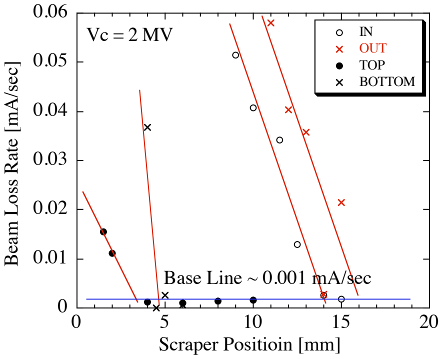

Figure 5: Beam loss rate as a function of the scraper position measured at a total rf voltage of 2 MV. Black open circles and red crosses show the rates measured using the inside and outside scrapers, respectively. Black closed circles and black crosses represent the rates measured using the top-side and bottom-side scraper, respectively. The red solid lines show the lines fitted by hand. The blue solid line shows the base line of the beam loss rate.

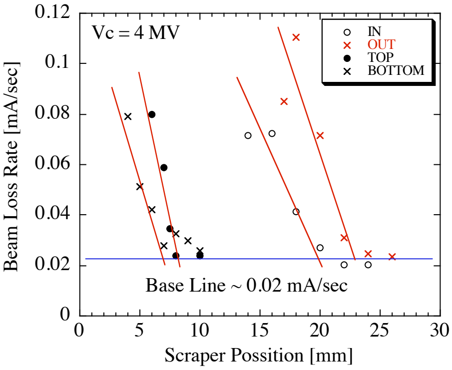

Figure 6: Same as the figure 5, but measured at a total rf voltage of 4 MV.

Observation of the Turn-by-turn Beam Profile

The evidence of the extension of the transverse beam profile, when the PQM was excited, was obtained using a beam scraper. In order to perform a cross check, we observed the turn-by-turn beam profile of the stored beam before and after the excitation of the PQM using a fast gate camera [2]. The experimental conditions were set to be almost the same as those of the beam scraper experiments. Figure 8 (a) shows the transverse beam profile and its horizontal projection before the excitation of PQM. Figures 8 (b) and (c) represent the beam profile measured at the 8th turn after the excitation for the total rf voltages of 2 MV and 4 MV, respectively. From the horizontally projected beam profiles, the measured beam sizes at the center regions of these two beams are almost the same horizontally when the profiles are assumed to be Gaussian distributions. However, the difference of the beam tails at 2 MV and 4 MV was clearly observed and the beam at 4 MV was obviously larger than that at 2MV. This was qualitatively consistent with the measured result using the beam scraper.

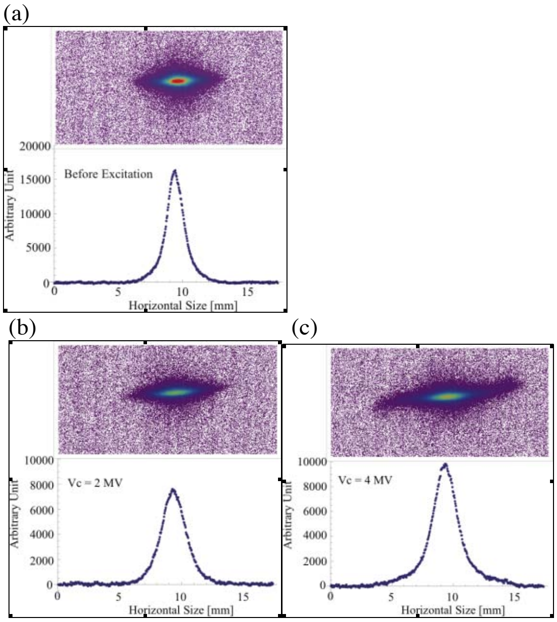

Figure 7: Turn-by-turn transverse beam profiles measured using a fast gate camera and its horizontal projection: (a) before the excitation of the PQM, (b) at 8th turn after the excitation at a total rf voltage of 2 MV, and (c) at 8th turn at a total voltage of 4 MV. The beam profile widow is 17.0 mm (Horizontal) x 8.5 mm (Vertical). The horizontal betatron function and dispersion function at the source point are 4.11 m and 0.79 m, respectively.

SUMMARY

Since September 2004, we have continued the beam injection study to accumulate the beam up to a current of 60 mA using the PQM injection system at the PF-AR. The strong dependence on a total rf voltage was observed in the stored beam current. In order to solve the cause of the dependence, various experiments were carried out. The experimental results of a beam scraper and a fast gate camera qualitatively agreed that the dependence resulted from the extension of the size of the stored beam coupled with the PQM excitation. We need further investigations for understanding the mechanism of the beam size extension. For example, the dependency on the total rf voltage may suggest the contribution of the bunch length and single bunch instability. And we will survey the beam loss point in the next experiment.

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REFERENCES

[1] K. Harada, Y. Kobayashi, T. Miyajima and S. Nagahashi, Phys. Rev. ST Accel. Beams **10** 123501 (2007).
[2] T. Mitsuhashi and M. Tadano, Proc. of the PAC 2003, p2506.