SUPPRESSION OF HORIZONTAL BEAM OSCILLATION BY FAST KICKER MAGNET SYSTEM IN SPRING-8 STORAGE RING

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Abstract

In a top-up operation at the SPring-8, a horizontal beam oscillation had been excited because the injection bump orbit is not closed perfectly. To overcome this problem, we had made an effort to reduce the residual beam oscillation. By these improvements the average amplitude of residual oscillation has now been suppressed to the level of less than 0.1 mm. Still remaining relatively large residual oscillation comes from a non-similarity of a temporal shape of magnetic field of four bump magnets especially at the rising part. We then started a development of a fast kicker magnet system to give a counter kick to this part of the residual beam oscillation. A key technology in this system is how to generate a large pulsed current in a short period to meet the oscillation characteristic. A newly developed fast pulsed power supply can generate a current of about 250 A, which corresponds to a magnetic field of 3.80 mT, with a pulsed width of 0.8 μs. Recently, we succeeded in the suppression of the horizontal beam oscillation by 67% at the rising part of the field of the bump magnets by using this kicker system.

INTRODUCTION

The SPring-8 has been started the top-up operation from May 2004 [1] to improve the effective life time because the short beam life time due to Touchchek effect reduces the brightness of the X-ray [2]. At the beam injection, a injection bump orbit is formed using four pulsed bump magnets. Because the pulse width of the magnet is 8.4 μs which corresponds to two turns of revolution time at SPring-8 storage ring (SR), if the bump orbit is not closed perfectly, the horizontal betatron oscillation of stored beam is excited. And this oscillation degrades the quality of the X-ray. So we tried to close the injection bump orbit and to suppress the oscillation amplitudes of stored beam to acceptable level for SR users [3]. The oscillation amplitude was reduced by a factor of about 10 by our many efforts done in 2004. However, we need furthermore reduction of the oscillation amplitude to introduce the new filling mode:10 mA single bunch + 4/7 uniform multi-bunch filling. We had aimed at giving a counter kick to this spike-like oscillation as a feed-forward scheme. However, there is no commercially available power supply system which could generate a short pulse of 0.8 μs with a large current output of more than 150 A. So, we had started the development of fast kicker power supply system in 2007. We could make the power supply system to be able to suppress the oscillation completely in 2009. We succeeded in the suppression of the oscillation amplitude by the developed a fast kicker magnet system. We will describe the detail setup of the fast kicker magnet system and how to suppress the oscillation amplitude.

OVERVIEW OF THE EXPERIMENT

The experimental system consists of a horizontal fast kicker magnet system (HK), a large current generation compact driving power supply (CDPS) system, single pass electron beam position monitor (SPBPM) system. HK system was installed in a place with a large horizontal betatron function (22.574 m) far away from the center of bump magnets by 1042.3 m to give a counter kick to electron beam effectively. Trigger timing signals which are synchronized with the beam injection of 1 Hz repetition are distributed to the HK and the SPBPM through the optical fibers. Using these trigger signals, the beam position can be recorded turn by turn up to 4096 turns at 288 points in the ring synchronized to the bump fire timing. In this measurement a single bunch beam is stored to obtain the beam position at the specified timing. By repeating the measurement with shifting the trigger timing of the bump magnets by 100 ns steps, we can get the oscillation amplitude at the whole timing of the pulsed bump magnetic field. To give a counter kick to spike-like horizontal oscillation, we adjusted the timing by following procedures. First, we measured the waveform of the leakage of injection bump orbit without exciting the counter kicker magnet. Next we measured the waveform of the kick angle of the counter kicker magnet without exciting the main bump magnets. Then, we adjust the counter kick timing overlapping the above two results.

FAST KICKER MAGNET SYSTEM

The required kick angle of the counter kicker is more than 30 μrad with a pulse width 0.8 μs. To generate this kick, an air-core magnet and LC resonant power supply were developed. The HK is consisted of a dipole air-coil magnet, a compact driving power supply circuit, an external high voltage power supply, and a timing module. The dipole magnet and the driving power supply are located inside the accelerator tunel. A photograph of kicker magnet

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system is shown in figure 1. We used two 1-turn air-coils in parallel to obtain a high frequency resonance. The coil is made of 2.0×2.2 mm copper wire with 250(L)×50(W) mm to fit the chamber size. Each coil was fixed by the Bakelite jig, which is attached to the chamber, to keep alignment. The original aluminum vacuum chamber was replaced by a ceramic one (KYOCERA) to reduce the eddy current by applying the pulsed magnetic field. The inner surface is coated by Ti-Mo of about 5 μm thickness to keep the low impedance to the stored beam. The chamber is cooled by air using fans attached in Bakelite jig not to keep the heat due to beam loading. Because the length of the kicker is

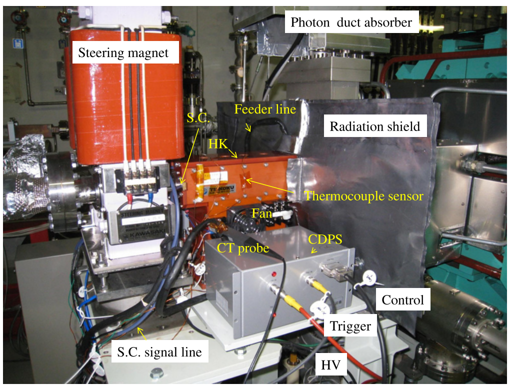

Figure 1: Setup of HK and CDPS.

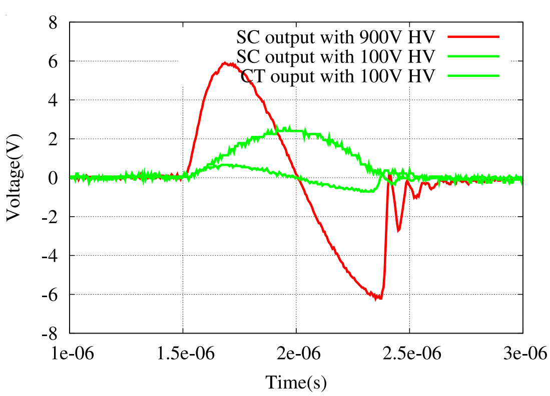

Figure 2: The output signals of SC in the case of high voltage of 900 V and 100 V. The CT probe result (10 mA/mV) in high voltage of 100 V is also overlaid.

0.25 m and the turn number is two, the excitation current of 250 A is needed to achieve the required kick angle. The CDPS was installed as close as possible to the coil within 30 cm to reduce inductance of the feeder lines. Based on this conceptual design, the size of the CDPS had to be small as much as possible. To realize a compact power supply system, we separated the high voltage power supply part from CDPS. The feeder lines are also paid much attention to reduce the inductance. The total inductance of the coils and the 0.8 m feeder cables was suppressed to about 1 μH based on this conceptual design. The size of accomplished CDPS was 200(L)×120(W)×150(H) mm. A radiation shield was installed to protect the CDPS's from the beam radiation in the accelerator tunnel. To realize the fast rising time, we used MOSFET as a switching device instead of use of an IGBT. We used six parallel connected MOSFET's of 1000 V high voltage resistant in CDPS to get above kick performance. The high voltage of 950 V was supplied by external high voltage power supply located in maintenance hall to get maximum output current. To turn on the MOSFET's of each CDPS at the same time, the delay generator (DG645) was used to make a trigger TTL pulse of a 5 V. The output current of each CDPS was monitored in real-time by each search coil (SC) which is inserted between the chamber outside surface and Bakelite jig inside. The monitored data was taken by the oscilloscope as shown in figure 2. In a setup condition of the figure, because we used the CT probe to calibrate the SC output, the output signal height was smaller than one in the actual operation setup by 8.3% due to the probe inductance. Then, the output current was also controlled by changing the voltage of external power supply remotely. Finally, we could get generate a half sine waveform with the maximum peak current of 270.6 A/coil with a pulse width of 0.8 μs at a bench test without the ceramic chamber. The peak current corresponds to the 3.16 mT in the center field. Under the actual set up condition with chamber, the current is reduced to 247.4 A by 9∼10 % due to the eddy current of ceramic chamber. An available kick angle by integrated magnetic field of 0.25 m magnet length reached 33.23 μrad for 247.4 A/coil in 8 GeV beam energy, which was enough level to suppress the oscillation.

RESULTS

Because the position of the bump magnets and that of the HK magnet are fixed, the phase advance of the betatron oscillation between these magnets is fixed. But we can adjust the phase by changing the turn number to trigger the HK with a step of fractional part of the betatron tune. So, first of all, we tried to find the better oscillation phase to give a counter kick effectively. In this measurement, the excitation current of the kicker is kept to be 200.2 A. The timing adjustment is done by following procedures:first, the trigger timing of the HK was adjusted to meet the oscillation peak by HK to the horizontal oscillation peak in first turn, second, HK was fired at the timing shifted by the revolution time of SR. Figure 3 shows the turn number dependency of the oscillation reduction efficiency. The horizontal axis is the turn number from the injection timing turn. The reduction efficiency was calculated by the ratio of the oscillation amplitude after giving a kick to that before giving a kick. The error of 7.8% mainly came from the oscillation due to the timing jitter of the main bump magnet power supplies. The lines are fitting results by $\mathrm{A}\sin(0.15\mathrm{B}+\mathrm{C})$ based on the horizontal tune of 40.15. We found that the better kick timing to maximize the suppression effect is third turn in order to suppress the oscillation in an early turn number.

Secondly, we preciously adjusted the kick timing shift-

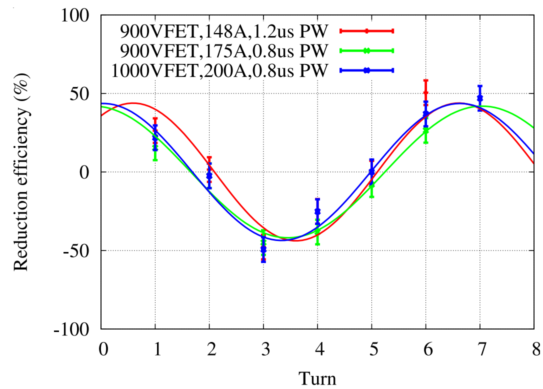

Figure 3: The turn number dependency. Each plots show the survey results by CDPS developed up to now. The current output and kicker pulse width are deferent. Blue plots are the results of accomplished CDPS in this time.

ing the timing by a 0.1 μs step near third turn kick timing as shown in figure 4. In this search, the kick power was fixed 200.2 A. When kick timing was adjusted to the horizontal oscillation peak position, the suppressed oscillation amplitude was minimized only at the oscillation peak. The blue line in the figure shows the suppressed oscillation result at the most effective timing. We got 67% suppression of oscillation amplitude. From this figure, we can find an another information about required pulse width. When shifting the kick timing only by 0.1 μs step, the suppressed oscillation shape became the v-like peak by increasing of the oscillation amplitude out of the target peak as a result of giving a kick at a part of skirt of kicker pulse. We concluded that the sufficient pulse width to suppress just a peak of the horizontal oscillation is less than 0.8 μs at least.

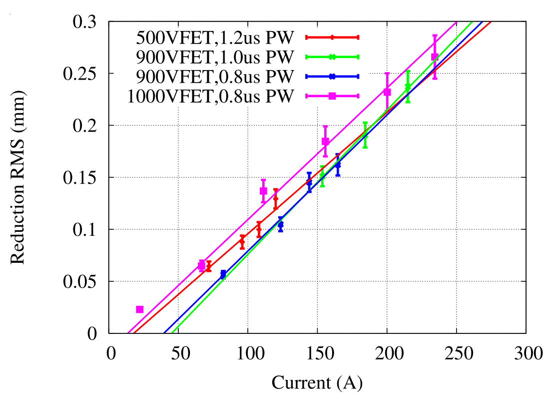

Figure 4: The precious timing adjustment.

Finally, we studied the kicker power dependency of suppressed oscillation amplitude keeping the kicker pulse width. Figure 5 shows the reduction RMS (mm), which is deference between before giving a kick and after that, to output current. Each plot shows the results by using CDPS of different performance. The resistant high voltage of FET, the reached maximum output current, and the minimum kick pulse width (PW) are different. Though we could easily achieve the high current output with kicker pulse width of more than 1.0 μs by using the higher voltage resistant FET, we could not achieve enough current with kicker pulse width of 0.8 μ. After many improvement efforts, we got a higher current output and the oscillation reduction by 0.28 mm (RMS) as shown by aqua color line. As a result, we succeeded in the suppression of the horizontal oscillation after three turns in the kick power condition of 247.4 A. The suppressed oscillation amplitude is an enough negligible level to SR users as shown in figure 6.

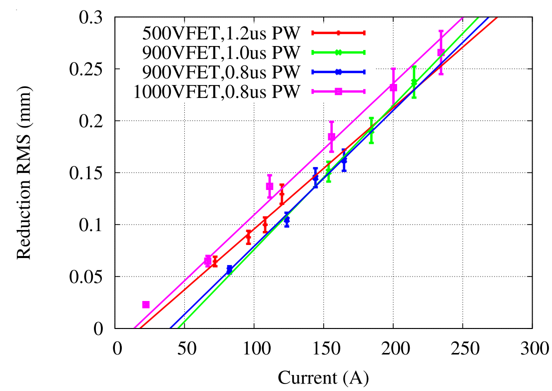

Figure 5: The kicker power dependency of the suppressed oscillation amplitude.

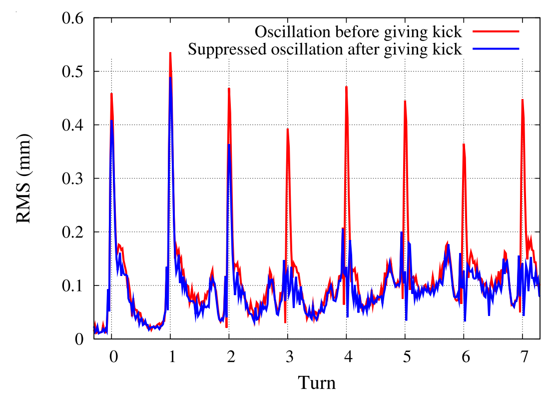

Figure 6: The suppressed horizontal oscillation by optimized counter kick.

CONCLUSION

By using developed fast pulsed kicker system (maximum current of 247.4 A with a pulse width of 0.8 μs), we succeeded in the reduction of the oscillation amplitude by 67% which promises a perturbation free top-up operation. We will try the new filling mode in the near future.

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