INJECTION PERFORMANCE WITH A TRAVELING WAVE KICKER MAGNET SYSTEM AT THE PHOTON FACTORY STORAGE RING

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Abstract

At the Photon Factory storage ring (PF-ring), four traveling wave kicker magnets were installed to obtain a wide acceptance for the injected beam in the high brilliant optics. The pulse shape and the excitation curve of the kick angles were measured using the stored beam. The phase-space motion of the stored beam after the excitation of the injection bump kick was measured. We achieved an injection speed more than 1.0 mA/s at a repetition rate of 12.5 Hz.

INTRODUCTION

The Photon Factory (PF) ring is a 2.5 GeV electron storage ring as a dedicated synchrotron radiation source. In 1994, we started the high-brilliant project. In this project, we modified the optics of ring to reduce the horizontal emittance from 130 nm·rad to 27 nm·rad [1]. The dynamic aperture was reduced to four times smaller than previous optics by this modification [2]. Due to the narrow dynamic aperture, we encountered some difficulties in the design of the injection with existed kicker magnets. To solve the difficulties, we applied kicker magnets having a shorter pulse length and a larger kick angle. We designed and constructed new travelling-wave type kicker magnets to realize these requests [3]. In October 2002, the kicker magnets were installed in the ring and started the operation. In this paper, it is described about the performance of the kicker magnets and the measured coherent oscillations of the stored beam using the actual beam.

OPTICS AORUND THE KICKER MAGNETS AND INJECTION BUMP

The square root of horizontal beta function (upper part) and the designed injection bump (lower part) with the lattice configuration in the injection section are shown in Fig. 1. The kicker magnets are named K1, K2, K3 and K4 from the upper stream of the ring. The principal parameters are listed in Table 1.

Table 1: The parameters of the kicker magnets.

Pulse length	1.3 μsec
Total magnet length	400 mm
Gap height	60 mm
Maximum voltage	15 kV
Maximum kick angle at 2.5 GeV	4 mrad

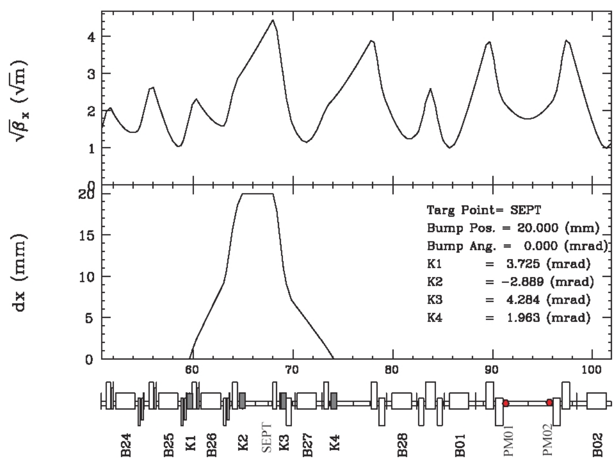

Figure 1: The square root of horizontal beta function (upper part) and the designed injection bump (lower part) are shown with the lattice configuration in the injection section.

PHASE-SPACE MONITOR

A pair of the beam position monitors (BPMs) is used for a phase-space monitor. The monitors are installed at the both end of long straight section. The distance between the monitors is 4.3 m [4]. The each monitor has six button-type electrodes, and the electrode is independently connected to the turn-by-turn detection circuit. The block diagram of the circuit is shown in Fig. 2.

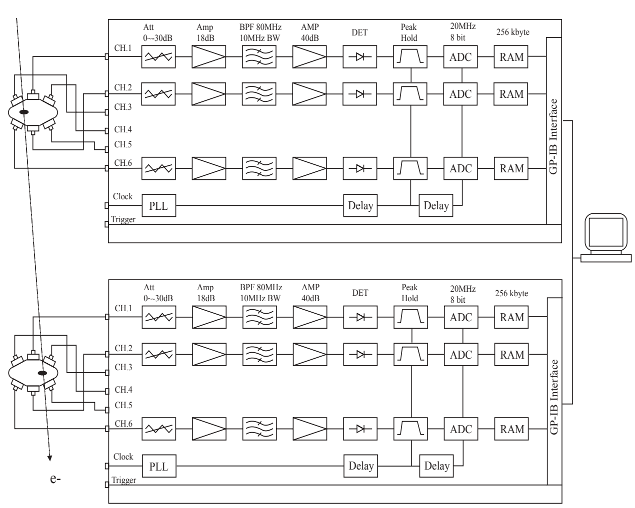

Figure 2: Block diagram of the turn-by-turn detection circuit.

The circuits consist of variable attenators, RF amplifiers, band-pass filters, peak detectors with a sample hold, 8-bit 20MHz ADCs and 256 kbyte memories. The data acquisition is started with the external trigger. The analog signals from the electrodes are desitized within a revolution period of 624 nsec. The desitized data are stored in the memories and sent to on-line computer through GP-IB when the memories become full.

MEASUREMENT OF THE PULSE SHAPES AND EXCITATION CURVES

We measured the pulse shapes and the excitation curves of the kicker magnets through the coherent oscillation of the stored beam. The oscillation was produced by the excitation of the magnets. The measurements were carried out using the single-bunch beam of 5 mA. The turn-by-turn position and angles of coherent oscillation were measured using the phase-space monitor. Figure 3 shows the block diagram of the trigger circuits for four kicker magnets. The timings of trigger pulses are controlled using independent four delay modules. The measurements of pulse length were carried out by changing the delay time of trigger pulses from 0 nsec to 650 nsec by 50 nsec step. The excitation curves of the kick angle were measured by changing the output voltage of power supplies from 2 kV to 5 kV by 1 kV step.

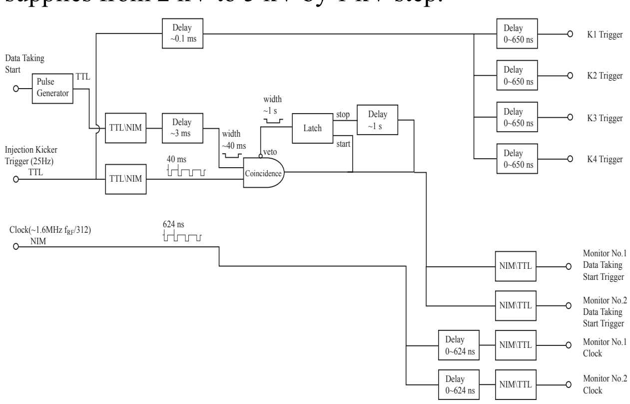

Figure 3: Block diagram of the trigger circuits for the kicker magnets, which is controlled by independent delay modules. The block diagram of data taking timing is also shown.

MEASUARED RESULTS

The turn-by-turn beam positions are evaluated by the following equations,

$$\begin{cases} U(n) = \dfrac{v_1(n) - v_3(n) - v_4(n) + v_6(n)}{v_1(n) + v_3(n) + v_4(n) + v_6(n)} \\ V(n) = \dfrac{v_2(n) - v_5(n)}{v_2(n) + v_5(n)} \end{cases} \quad (1)$$

$$x(n) = \sum_{i=0}^{6}\sum_{i=0}^{6} k_x(i,j) U^i(n) \ V^j(n) \quad (2)$$

where $v_i(n)$ is the digitized data of *i-th* channel of the BPM, *n* turn number, and k_x the two-dimensional transfer coefficients to the beam position. The coefficients are calculated using a mapping data of the BPM. Since only the drift space exists between the monitors, the positions and the angles of the beam at the center of the monitors are simply calculated by the following equation,

$$\begin{cases} x_M(n) = \dfrac{x_{1M}(n) + x_{2M}(n)}{2} \\ x'_M(n) = \dfrac{x_{2M}(n) - x_{1M}(n)}{\ell_M} \end{cases} \quad (3)$$

where ℓ_M is the distance. The results plotted until 3rd turn after the kick of K4 magnet are shown in Fig. 4.

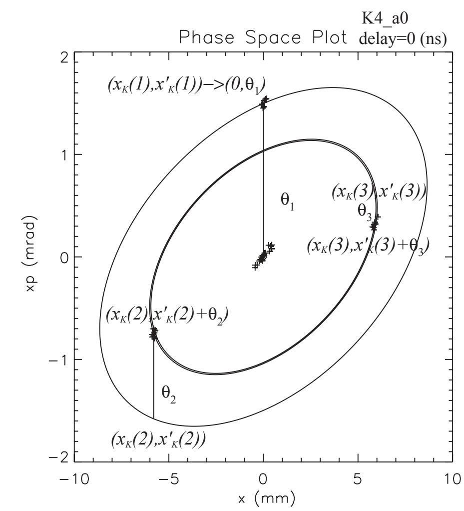

Figure 4: Phase-space plots after the kick by K4 magnet. The crosses display the measured data. The solid lines represent the calculated ellipse.

The solid line in the Fig. 4 calculated by the following equation with the Twiss parameters listed in Table 2,

$$\begin{cases} \gamma_K \ x_K(n)^2 + 2\alpha_K \ x_K(n)x'_K(n) + \beta_K \ x'_K(n)^2 = \beta_K \theta_n^2 \\ n = 1,2,3 \end{cases} \quad (4)$$

Table 2: Twiss parameters at the kicker magnets and the center between two monitors. The horizontal phase advances $\Delta\psi_x$ from the monitors are also listed.

	K1	K2	K3	K4	C.Mon.
β_x (m)	4.000	6.840	6.206	5.781	5.220
α_x	-2.111	-0.8378	3.960	-0.4671	0.110
$\Delta\psi_x$	-9.665	-8.129	-7.712	-5.770	0.000

where θ_n is the kick angle of n^{th} turn. During this calculation, we assume that the betatron oscillation after the kick is linear. Using the Eq. 4, we can easily evaluate the kick angle. The measured result of the pulse shape in the kicker magnets is shown in Fig.5. The horizontal axis denotes the time *t*, which is calculated as follows,

$$\begin{cases} t = n \times \tau_{rev} - m \times \tau_{delay} \\ n = 1, 2, 3 \\ m = 1, 2, \cdots, 14 \end{cases} \quad (5)$$

τ_{rev}: revolution period (624 nsec)

τ_{delay}: delay time (50 nsec)

n: turn number

m: number of the measurements

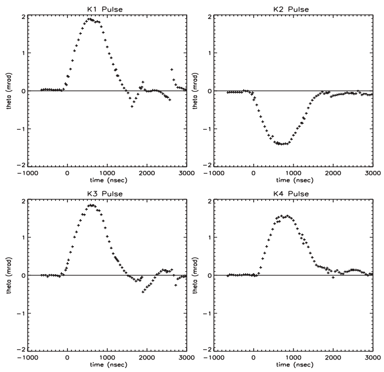

Figure 5: Pulse shapes of kicker magnets measured at the voltage of 5 kV. The crosses display the measured data and solid line show the normalized pulse shape obtained by the field measurement.

The excitation curve of the kicker magnets is shown in Fig. 6. The results of the pulse length and kick angles at 5kV are summarized in Table 3. From the Fig. 5, we found the timing of the K4 magnet is delayed by 200 nsec from that of the other magnets. The pulse length of K2 magnet was about 200 nsec longer. We adjusted the timing of K4 magnet to those of other magnets. We do not understand the cause of the longer pulse length. From the Fig. 6, the kick angles of four magnets varied up to 20% in this measurement.

Table 3: Kick angles, and pulse lengths measured at the voltage of 5 kV.

	K1	K2	K3	K4
θ_k (mrad) at 5 kV	1.88	1.41	1.84	1.56
τ_{total} (nsec)	1626	1874	1611	1611

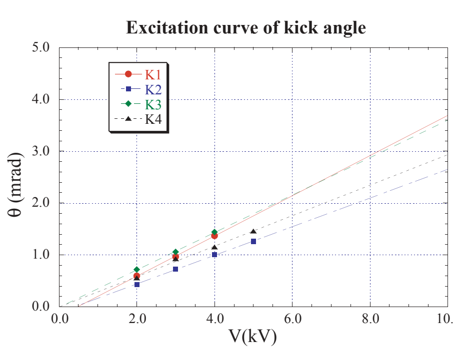

Figure 6: Excitation curves of the kick angle. The closed circles display the measured data and solid line shows the excitation curve obtained by fitting the data.

COHERENT OSCILLATION OF THE STORED BEAM

The phase-space motion of the stored beam after the excitation of the injection bump kick was measured. The result is shown in Fig. 7. Since the injection bump was not completely closed, the coherent oscillation of the stored beam was exited. However, this coherent oscillation quickly damped turn by turn. Actually, we found that the coherent oscillation of the stored beam had no influence to the beam injection.

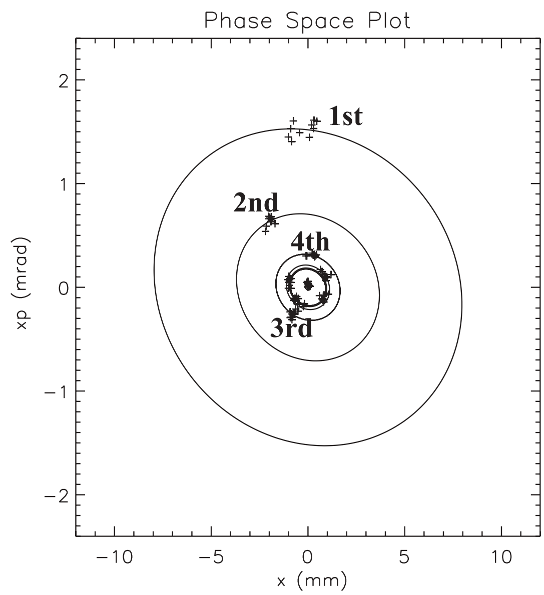

Figure 7: The phase-space plot of the coherent oscillation measured after the excitation of the injection bump.

CONCLUSIONS

Four traveling wave kicker magnets were installed in October 2002. The performance of injection bump was investigated using the stored beam. The pulse shapes and the excitation curves of the kick angle were individually measured using the phase-space monitor. We found the timing of K4 magnets was delayed by 200 nsec. The pulse lengths of K1, K3 and K4 agreed to each other except K2. The kick angles varied up to 20%. In fact, these variations were no problem in the beam injection. Since these variations has not observed in the magnetic field measurement [3], we do not understand the cause of the variations now, and we will investigate it in the future. Consequently, we achieved an injection speed more than 1.0 mA/s at a repetition rate of 12.5 Hz.

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