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BEAM BASED MEASUREMENT OF INJECTION PARAMETERS AT KEK-PF

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Abstract

Photon Factory storage ring (PF-ring) is the 2.5 GeV synchrotron radiation light source in KEK. After the earthquake hit in 2011, the injection efficiency using the conventional pulsed kicker and septum system has decreased. The primary cause of the problem seems to be the change of the injection parameters. To analyze the present injection parameter, we carried out the simulations [1] and beam studies. In this paper, we show the beam based estimation of the position and divergence angle of the injected beam at the exit of the injection septum magnet.

INTRODUCTION

At the PF-ring, the injection system consists of the conventional pulsed kicker and septum magnets. After the earthquake hit in 2011, the alignment errors of the beam transport and septum magnets increased, and the injection efficiency was deteriorated. To recover and improve the injection efficiency, investigation of the present injection parameters are essential. It is difficult to measure the precise location of the septum magnet due to its old design and complicated structure.

In synchrotron radiation facility, optimization of optics, correction of COD and adjustment of betatron tune, etc. are carried out. And then the injection beam is stored in the ring by adjusting the kicker parameters and the kick angle of the septum magnet and correction magnet of beam transport path. Beam-based information is important for adjustment of injection parameters. The beam-based measurement is used to analyze kicker parameters [2]. In this study, we beam-based measurement kicker parameters and injection parameters using BPM already installed without shifting alignment in another way.

To improve the pulsed local bump of the stored beam, the kicker parameters were measured with the fast phase space monitors [3] in 2003. With the recent improvement of the fast beam position monitors (BPMs), we can determine the current waveform of each pulsed kickers more easily and accurately. The initial position and divergence angle of the injected beam at the exit of the beam transport can also be measured by the fast BPMs in the ring. In this presentation, we show the results of the beam based measurements to fix the injection parameters of the PF ring.

OPTICS AND MONITOR

To measure the beam position, two fast BPMs at both sides of the straight section #2 are used. The lattice configuration for the measurement is shown in Fig. 1. From the measured beam positions at the both sides as x_1 and x_2, the phase space position (position x and divergence angle x') at the center of the straight section can be calculated as Eq. (1).

$$x = \frac{x_1 + x_2}{2}, \qquad x' = \frac{x_2 - x_1}{l} \tag{1}$$

Here $l =$ 8.83 m is the length between two BPMs where only two insertion devices are installed. During measurements, the gaps of all insertion devices are fully opened. With the ideal Twiss parameters and phase advances, the phase space information of the beam at the upstream position can be fixed. Twiss parameters and phase advance for the center of the straight section #2 and the injection point are listed in Table 1.

Table 1: Twiss Parameters at the Exit of the Septum Magnet and the Straight Section #2 between Two Monitors

Position	**α**	**β**	**Phase advance**
Straight section #2	2.38	44.6	6.73
Injection	-3.78	13.7	

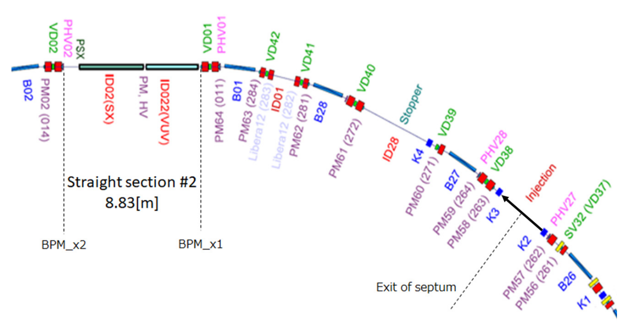

Figure 1: Lattice configuration for the measurement.

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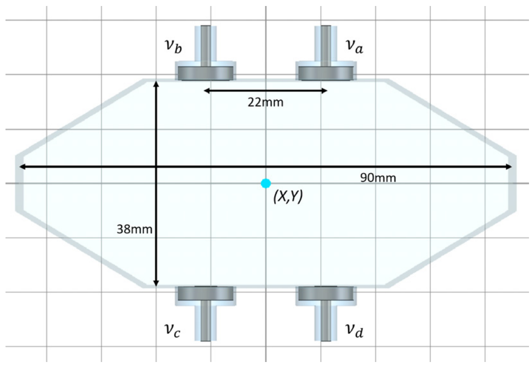

Figure 2: Cross section of the BPM duct.

The cross-section of the BPM duct is shown in Fig. 2. The voltage signal from electrodes are processed with commercial BPM analyzer (Libera Brilliance+ [4]). The signal is digitized with ADC (analog-to-digital converter) sampling rate of about 100 MHz. The revolution period of the beam is 625 ns, and the data is acquired for about 74 turns. The measurement starts with the external trigger (i.e., injection pre-trigger) and the digitized data are stored in ADC buffer.

Because of the large amplitude of the beam of the measurements, the non-linear terms of the BPM response should be precisely considered,

$$\begin{cases} U = \dfrac{v_a - v_b - v_c + v_d}{v_a + v_b + v_c + v_d} \\ V = \dfrac{v_a + v_b - v_c - v_d}{v_a + v_b + v_c + v_d} \end{cases} \tag{2}$$

$$x = \sum_{i=0}^{3}\sum_{j=0}^{3} k_x(i,j)U^i V^j \tag{3}$$

where, v_i is the signal size from electrodes, $k_x(i,j)$ is coefficients of i^{th} order polynomials. Fig. 3 shows the mapping results of the BPM with using 3rd order coefficient listed in Table 2. When the amplitude of the beam is larger than the position of the electrode (for example, 11 mm for the horizontal case), it may be difficult to keep the resolution of the measurements.

Table 2: Coefficients of 3rd Order Polynomials

Coefficients	Horizontal	Vertical
k(0,0)	0.000	0.000
k(1,1)	17.120	0.000
k(1,2)	0.000	16.432
k(2,1)	0.000	0.000
k(2,2)	0.000	0.000
k(2,3)	0.000	0.000
k(3,1)	18.829	0.000
k(3,2)	0.000	-11.477
k(3,3)	-27.138	0.000
k(3,4)	0.000	7.431

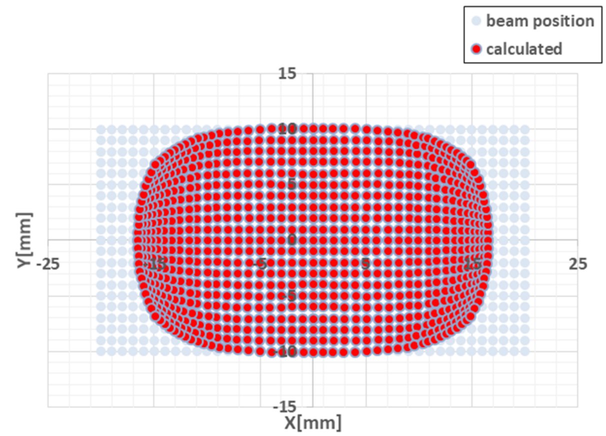

Figure 3: Plot of calculated position by 3rd order coefficient.

MEASUREMENT OF THE STORED BEAM

Firstly, we measured the stored beam position without kicker bump as the standard orbit ("golden" closed orbit) to fix the central axis of the betatron oscillation. The measurement carried out with the single-bunch of 3 mA. The results of the phase space position at the center of straight section #2 is shown Table 3.

For the analysis of the voltage waveform, we pick up the ADC data in the buffer at the revolution cycle. The ADC Count has a value proportional to the charge of the beam. Since the sum of the ADC counts corresponds to the signal v_i from the electrodes.

Table 3: The Parameters of the Phase Space

	position[mm]	angle[mrad]
Horizontal	-1.22 ± 0.09	0.53 ± 0.03
Vertical	1.65 ± 0.07	-0.12 ± 0.02

MEASUREMENT OF THE PULSE SHAPES OF KICKER MAGNETS

We measured the pulse shapes of the kicker magnets of the stored beam by the changing the kicker delay time from 0 to 2500 ns by 25 ns step. The revolution period is about 625 ns and the design width of the half sine kicker waveform is 1.2 ns. The measurement of the pulse shapes carried out using the stored beam of 3 mA single-bunch. The oscillation was produced by exciting individually K1 to K4 in Fig. 1 with 0.4 mrad kick angle. The measurement results are shown Fig. 4.

Table 4: Kick Angle and Pulse Length (zero-to-zero)

	K1	K2	K3	K4
Kick angle [mrad]	-0.454	0.351	-0.452	-0.539
Pulse length [nsec]	1550	1625	1400	1625

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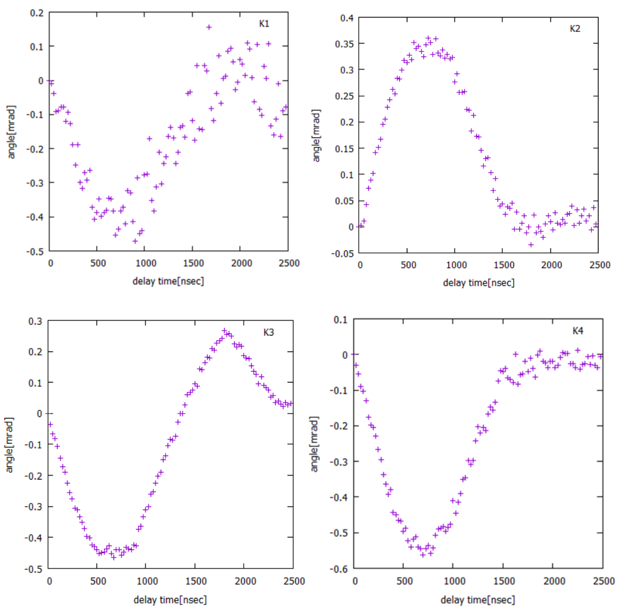

Figure 4: Pulse shapes of kicker magnets (0.4 mrad).

The measured kick angles were different from the set value of 0.4 mrad. The kick angle and width of K3 are different from other three kickers. Also, the measured pulse length were different from the set value of 1300 nsec. We found to be the stored beam deviated from the peak of the pulse shapes is multi-kicked by kicker magnets due to pulse length. The result has suggested that injection bump was not completely closed.

MEASUREMENT OF THE INJECTED BEAM

We finally measured the injected beam position without kicker bump by the same method. For the injected beam, we only use the BPM data for the first pass. The obtained phase space positions were traced back to the injection point using the ideal transfer matrix.

The measurement of the injected beam carried out using the single-bunch of 1 mA/s (1 nC bunch current) at a repetition rate of 1 Hz and plotted 100 shots in phase space. The measurement results of the straight section #2 are shown in Fig. 5. The estimated beam position at the exit of the septum (entrance of the ring) is shown in Fig. 6. The averaged value was summarized in Table 4.

Table 5: The Parameters of the Phase Space of Fig. 5 and Fig. 6

Horizontal	x[mm]	x'[mrad]
Straight section #2	1.89 ± 0.88	3.53 ± 0.22
Injection	37.6 ± 2.3	4.43 ± 0.31
Vertical	**y[mm]**	**y'[mrad]**
Straight section #2	0.92 ± 0.70	-0.43 ± 0.01
Injection	0.06 ± 0.23	0.99 ± 0.23

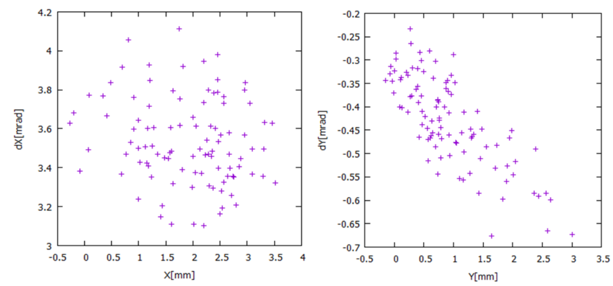

Figure 5: Measured phase space at the straight section #2.

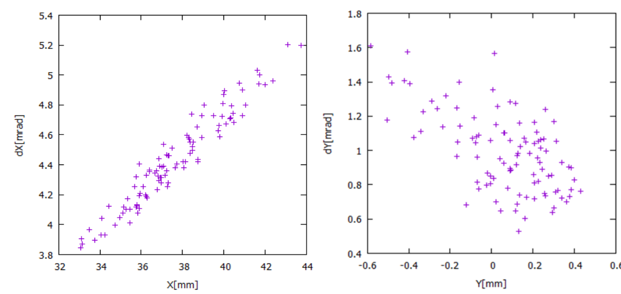

Figure 6: Estimated phase space at the injection point.

SUMMARY

To recover and improve the injection efficiency of the PF ring, we measure the kicker parameters and injected beam parameters by the beam based method. The pulse shapes of the kicker magnets were measured with reasonable precision and the difference from the design values were found. Due to the characteristics of K3, we cannot close the kicker bump for the multi-bunch mode.

The averaged value of the measured injection points was found to be (37.64 mm, 4.43 mrad) at the exit of the beam transport. The resulted horizontal position may be a bit too far from the ring orbit comparing with the designed hardware configuration. This result seems to be one of the reasons for the deterioration of the injection efficiency.

We will make further machine study and simulations to improve the accuracy. For the next step, we consider the non-linear effects of the ring components and distortions of Twiss parameters.

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