Development of Double Kicker System in KEK-ATF

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Abstract

A double kicker system which extracts the low emittance multi-bunch beam from damping ring stably was developed in KEK-ATF for future linear collider. The system consists of one pulse power supply and two kicker magnets which have the same structure and compensates the kick angle jitter by tuning optics between two kickers. The performance of the system was studied with cavity BPMs to measure the orbit jitter of extracted beam in single bunch operation. Comparing single kicker extraction,the double kicker system have the effect of jitter reduction.The results of the study is described in detail.

1 INTRODUCTION

KEK-ATF is an accelerator test facility for injector part of a future electron-positron linear collider. The purpose of ATF is to develop accelerator technologies that can stably supply to the main linac ultra-low emittance multi-bunch beam to achieve high collision luminosity as required for linear collider [1][2].

Stabilization of the low emittance beam extracted from the damping ring is extremely important, because the position jitter would be magnified by transverse wakefields in the main linac and reduce the luminosity. Therefore, the jitter tolerance of extraction kicker magnet is very tight and estimated to be 5×10^{-4} assuming $\beta_x = 10$m[3]. In ATF, double kicker system was developed to achieve this tolerance [4].

2 DOUBLE KICKER SYSTEM

The double kicker system consists of one pulse power supply and two kicker magnets which have the same structure as shown in Figure 1. The first kicker is placed in the damping ring for beam extraction and the second one in the extraction line for jitter compensation.

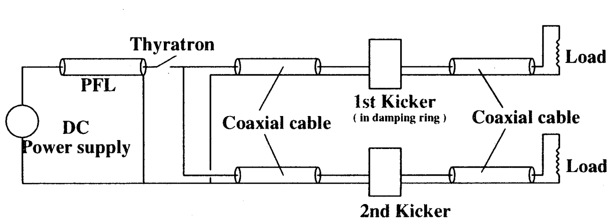

Figure 1: Diagram of kicker hardware

It is, in principle,able to compensate kick angle variation of the first kicker by tuning optics between two kickers. When the first kicker has a kick angle variation $\Delta\theta_1$ and the second one has $\Delta\theta_2$,$(\Delta x, \Delta x')$ after the kick of the second kicker can be written as

$$\begin{pmatrix}\Delta x\\ \Delta x'\end{pmatrix} = M_{1\to2}\begin{pmatrix}0\\ \Delta\theta_1\end{pmatrix} + \begin{pmatrix}0\\ \Delta\theta_2\end{pmatrix} \quad (1)$$

then,

$$\Delta x = m_{12}\Delta\theta_1, \Delta x' = m_{22}\Delta\theta_1 + \theta_2 \quad (2)$$

Here, $M_{1\to2}$ is a transfer matrix from the first kicker to the second one and m_{12} and m_{22} are matrix elements,

$$m_{12} = \sqrt{\beta_1\beta_2}\sin\Delta\psi \quad (3)$$

$$m_{22} = \sqrt{\frac{\beta_1}{\beta_2}}(\cos\Delta\psi - \alpha_2\sin\Delta\psi) \quad (4)$$

where suffix 1 shows the function of the first kicker and suffix 2 shows the second kicker and $\Delta\psi = \psi_2 - \psi_1$ is phase advance.

In order to compensate the kick angle variation, m_{12} must be zero,that is, phase advance $\Delta\psi$ must be π. When the phase advance of the two kickers is π,

$$\Delta x' = -\sqrt{\frac{\beta_1}{\beta_2}}\Delta\theta_1 + \Delta\theta_2 \quad (5)$$

is obtained. There is strong correlation between $\Delta\theta_1$ and $\Delta\theta_2$ pulse by pulse, because one power supply sends pulse into two identical kicker magnets. Therefore compensation can be done by adjusting the ratio of β function.

3 ATF EXTRACTION LINE

The layout of the extraction line is shown in Figure 2. The beam is extracted from damping ring by one pulse kicker magnet and three DC septum magnets. The second kicker for jitter compensation is located at the middle of the extraction line.

The optics of the extraction line is shown in Figure 3. The high dispersion region was placed at upstream of the extraction line to measure momentum spread and fluctuation. On the other hand, beam diagnostic section at downstream was designed dispersion free to minimize the effect of its contribution to beam size and position jitter in measurement of low transverse emittance.

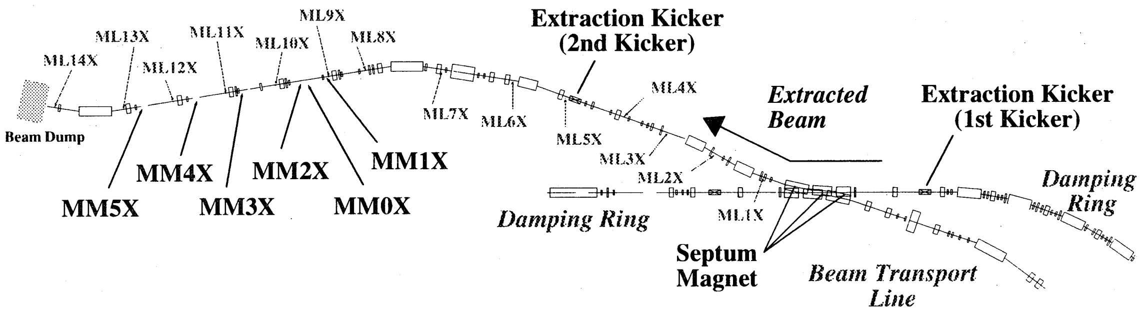

Figure 2: Layout of the Extraction line

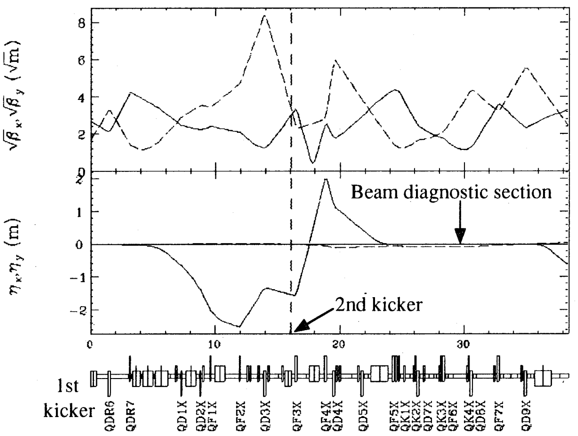

Figure 3: Optics of the Extraction line

4 CAVITY BPM

Cavity Beam Position Monitor (BPM) was developed in collaboration with BINP and installed in the beam diagnostic section of the extraction line to measure orbit jitter.

Two different kind of cylindrical cavities are used to measure beam position. One is sensor cavity to detect TM_{110} mode signal,whose amplitude is proportional to the beam offset from the axis and the beam current. Another is reference cavity to measure the beam current and detect beam phase for reference using TM_{010} mode.

One reference cavity (MM0X) and five sensor cavities (MM1X-MM5X) were installed as shown in Figure 2. The resonance frequency was chosen for 6.426GHz considering beam path aperture and the cavity size.The estimated position resolution which depended on signal intensity was about 2μm when measurable dynamic range was 1mm. The resolution of existing strip-line BPM in the beam diagnostic section was about 20μm, so the cavity BPM was very useful for precise measurement of orbit jitter.

5 EVALUATION OF DOUBLE KICKER SYSTEM

We measured horizontal beam orbit jitter of the extraction line in single bunch operation and compared the performance of the double kicker system with the case of extraction without the second kicker which we defined as a single kicker mode. In single kicker mode, a DC dipole magnet was installed instead of the second kicker. The operation condition of the measurement was beam energy 1.28GeV, repetition rate 1.56Hz and beam intensity at the extraction line 8×10^9 electrons.

5.1 Horizontal displacement in the Extraction line

The horizontal beam position jitter in the extraction line comes from a beam jitter at the extraction point, a kick angle jitter of the extraction kickers and a momentum fluctuation of the beam. The horizontal displacement at a point after the second kicker can be written as

$$\Delta x^i = \Delta x^i_{inj} + \Delta x^i_{kicker} + \Delta x^i_p \tag{6}$$

where,

$$\begin{aligned}
\Delta x^i_{inj} &= R_{11}(1,i)\Delta x_{inj} + R_{12}(1,i)\Delta x'_{inj} && (7)\\
\Delta x^i_{kicker} &= R_{12}(1,i)\Delta\theta_1 + R_{12}(2,i)\Delta\theta_2 && (8)\\
\Delta x^i_p &= \eta_i \frac{\Delta p}{p} && (9)
\end{aligned}$$

Here, $R_{11}(1,i)$ and $R_{12}(1,i)$ are transfer matrix elements from the first kicker to the point i, $R_{12}(2,i)$ is from the second one. η_i is a dispersion at the point i and $\Delta p/p$ is momentum fluctuation of the beam.In single kicker mode, $\Delta\theta_2$ was zero because the DC dipole magnet was installed as the second kicker.

5.2 Analysis method

We obtained $(\Delta x, \Delta x')$ distribution came from kick angle jitter at the second kicker with the following procedure.

1. We measured horizontal beam position with 5 cavity BPMs and defined Δx^i as the measured displacement from the average position at each BPM.

2. Δx^i_p were obtained the measured dispersion by changing rf frequency in the ring and the measured momentum fluctuation at the high dispersion region with eq(9).

3. After subtraction Δx^i_p from Δx^i, $(\Delta x, \Delta x')$ at the second kicker were calculated using optics model.

4. We measured the beam position in the damping ring at the same time, the effect of beam jitter at the extraction point in damping ring was subtracted from $(\Delta x, \Delta x')$ in procedure 3.

5.3 Result of jitter reduction

Table 1 gives the result of jitter measurement with 5 cavity BPMs (MM1X-MM5X) and the measured dispersion and model value of R_{11} and R_{12} at each BPM in both modes. Figure 4 shows $(\Delta x, \Delta x')$ distribution came from kick angle jitter at the second kicker which was obtained the analysis mentioned in the section 5.2 and the result is summarized in Table 2.

Comparing the two modes, the double kicker system reduced the kick angle jitter 4.7 μrad down to 1.7μrad.Kick angle of the extraction kicker is designed 5 mrad,so the stability in the double kicker system was 3.4×10^{-4} in single bunch operation.

According to a simulation using position measurement error generated from Gaussian distribution, the upper limit of the measurable kick angle jitter is estimated to be 0.8 μrad assuming the position resolution of the cavity BPM is 2 μm. Therefore, it seemed that there are some errors in the compensation which were the optics setting errors between the two kickers and the change of the ratio of kick angle variation $\Delta\theta_1$ to $\Delta\theta_2$ during the measurement coming from the difference of pulse magnetic field of the two kickers and thyratron trigger time jitter and drift.

Table 1: Summary of jitter measurement and optics parameters at each cavity BPM

	Double		Single			
BPM Name	$\sigma_{\Delta x}$ μm	η_x mm	$\sigma_{\Delta x}$ μm	η_x mm	R_{11}	R_{12} m
MM1X	6.5	-10.2	19.8	-8.3	1.20	-6.03
MM2X	3.7	-5.7	14.2	-6.2	1.10	-4.63
MM3X	2.1	2.7	6.4	-4.0	0.49	-0.10
MM4X	11.2	5.8	25.5	1.2	-0.02	5.06
MM5X	9.9	5.7	24.2	3.5	-0.35	5.55

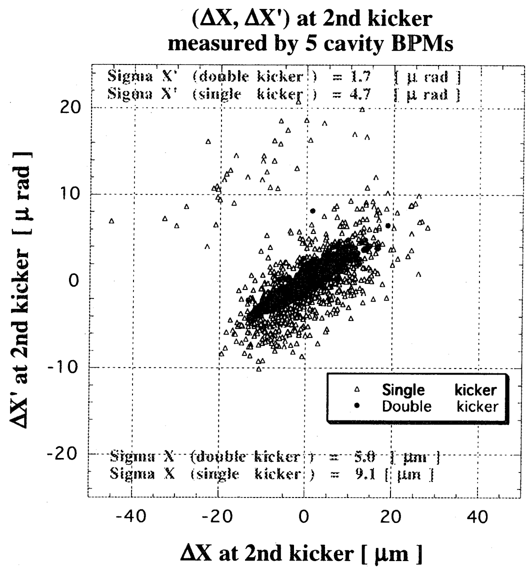

Figure 4: $(\Delta x, \Delta x')$ distribution came from kick angle jitter at the second kicker

Table 2: Comparison of jitter reduction

mode	$\sigma_{\Delta x}$	$\sigma_{\Delta x'}$
double kicker	5.0 μm	1.7 μrad
single kicker	9.1 μm	4.7 μrad

6 CONCLUSION

The performance of the double kicker system was studied with cavity BPMs which had high position resolution to measure the orbit jitter of extracted beam in single bunch operation. Comparing with the single kicker extraction,the double kicker system reduced the kick angle jitter 4.7 μrad down to 1.7μrad.

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