Double Kicker system in ATF

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Abstract

A double kicker system which extracts the ultra-low emittance multi-bunch beam stably from ATF damping ring was developed. The performance of the system was studied comparing an orbit jitter with single kicker extraction in single bunch mode. The position jitter reduction was estimated from the analysis of the extraction orbits. The reduction was confirmed for the double kicker system within a resolution of BPMs. More precise tuning of the system with a wire scanner has been tried by changing a β function at the second kicker to get more reduction of kick angle jitter. The results of these studies are described in detail.

1 INTRODUCTION

KEK/ATF is an accelerator test facility for an injector part of a future linear collider. It consists of an S-band injector linac, a beam-transport line, damping ring and extraction line [1]. The main purpose of ATF is to generate and measure ultra-low emittance multi-bunch beam (2.8nsec spacing, 20bunch) and develop technology that can stably supply the beam to the main linac.

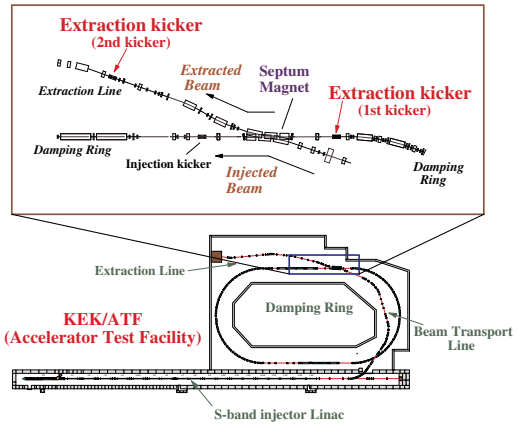

Figure 1: Layout of injection/extraction region of ATF

The stable beam extraction from the damping ring is essential for linear collider to achieve high luminosity, because the position jitter would be magnified by transverse wakefields in the linac and reduce the luminosity. Therefore, the jitter tolerance of extraction kicker magnet is very tight and estimated to be 5×10^{-4} assuming β_x = 10m[2]. It will be applied not only to a uniformity of pulse magnetic field for the tolerance of multi-bunch but to a pulse-to-pulse stability. In ATF, double kicker system was developed for the stable beam extraction [3]. The system uses two identical kicker magnets for beam extraction. The first kicker is placed in the damping ring and the second one for jitter compensation in the extraction line.

The ATF extraction kicker consists of 25 electrode pairs with ferrite loaded in a vacuum chamber. A ceramic tube with TiN coated inside is used for beam channel in the kicker in order to reduce an beam impedance. The specification of the kicker is summarized in Table 1.

Table 1: ATF Extraction Kicker magnet

Kick angle	5	mrad
Impedance	50	Ω
Magnet length	0.50	m
Magnetic field	513	Gauss
Rise and Fall time	60	nsec
Flat top	60	nsec
Maximum voltage	40	kV
Maximum current	800	A

2 DOUBLE KICKER SYSTEM

The double kicker system consists of one pulse power supply and two kicker magnets separated by phase advance π. It is, in principle, able to compensate kick angle variation of the extraction kicker in damping ring. When each kicker has a kick angle variation $\Delta\theta_1$ and $\Delta\theta_2$, (x, x') at the second kicker can be written as

$$\begin{pmatrix} x \\ x' \end{pmatrix} = M_{1\to 2} \begin{pmatrix} 0 \\ \Delta\theta_1 \end{pmatrix} + \begin{pmatrix} 0 \\ \Delta\theta_2 \end{pmatrix} \quad (1)$$

Here, $M_{1\to 2}$ is a transfer matrix from the first kicker to the second one. Since a phase difference of the two kickers is π,

$$\begin{pmatrix} x \\ x' \end{pmatrix} = \begin{pmatrix} -\sqrt{\frac{\beta_2}{\beta_1}} & 0 \\ -\frac{\alpha_2-\alpha_1}{\sqrt{\beta_2\beta_1}} & -\sqrt{\frac{\beta_1}{\beta_2}} \end{pmatrix} \begin{pmatrix} 0 \\ \Delta\theta_1 \end{pmatrix} + \begin{pmatrix} 0 \\ \Delta\theta_2 \end{pmatrix} \quad (2)$$

then,

$$x = 0, x' = -\sqrt{\frac{\beta_1}{\beta_2}}\Delta\theta_1 + \Delta\theta_2 \quad (3)$$

are obtained. When the two kickers are identical, that is $\Delta\theta_1 = \Delta\theta_2$, the variation could be canceled with the same β function. If the two kickers are not identical, compensation also can be done by adjusting β function. In case of multi-bunch extraction, only the similarity of the flat-top waveform between two kickers is required for the jitter reduction in each bunch. A tight flatness requirement for every bunch in a multi-bunch is not necessary.

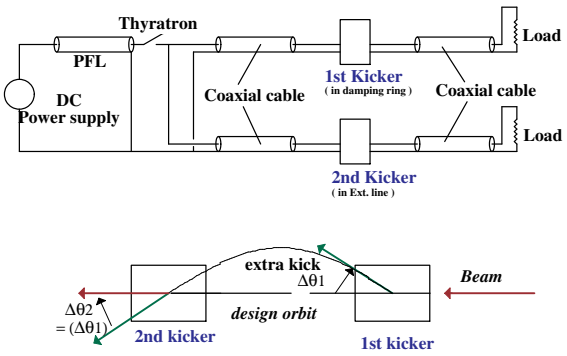

Figure 2: Double kicker system

3 ORBIT JITTER REDUCTION

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.

The operation condition at the measurement was single bunch mode, beam energy 1.3GeV, and repetition rate is 0.78Hz. The beam is extracted from damping ring to the extraction line by one kicker magnet and three DC septum magnets. Kick angle of the kicker is designed to 5mrad. In single kicker mode, a dipole magnet was installed instead the second kicker.

The beam orbit shot by shot was measured by strip-line BPMs in the extraction line [4]. Total 14 BPMs are used for the measurement and analysis.

3.1 Analysis method

The horizontal beam position jitter in the extraction line came from 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

$$\begin{aligned} \Delta x_i &= \Delta x_{kicker} + \Delta x_{momentum} \\ &= R_{12}(1,i)\Delta\theta_1 + R_{12}(2,i)\Delta\theta_2 + \eta_i \frac{\Delta p}{p} \quad (4) \end{aligned}$$

where $R_{12}(1,i)$ is a transfer matrix component from the first kicker to the point i , $R_{12}(2,i)$ is from the second one and η_i is a dispersion. In this analysis, $\Delta\theta_1$,$\Delta\theta_2$ and $\Delta p/p$ were obtained by fitting the measured displacement from the average position at BPMs with eq(4). Δx_{kicker} was calculated by subtraction $\eta_i \frac{\Delta p}{p}$ from the displacement at each BPM. In single kicker mode, the same analysis also has been done, but $\Delta\theta_2$ was set to zero because the dipole magnet installed as the second kicker is DC magnet.

3.2 Result of jitter reduction

Table 2 shows the comparison of the position jitter caused by kick angle variation in both modes at the BPM where has the maximum R_{12} from the kicker.

σ_{kicker} was calculated by using model value of R_{12} and fitting value of kick angle variation of each shot. The effect of jitter reduction was compared in the two kick angle region. As a result, the double kicker system reduced the jitter down to the resolution of BPM which is about 20μm in case of small kick variation, however the reduction rate was not sufficient in case of large kick variation. In both cases, the position jitter reduction was observed for the double kicker configuration, however, a precise tuning of the system and a high resolution position monitor are still necessary for a further reduction.

Table 2: Comparison of position jitter measurement

mode	# of meas.	σ_{kicker} [μm]	# of meas.	σ_{kicker} [μm]
double	115	37	181	24
single	60	78	248	34
	$\Delta\theta_1 \geq$0.007mrad		$\Delta\theta_1 \leq$0.007mrad	

4 OPTICS TUNING

In order to get more jitter reduction, β function at the second kicker was surveyed using high resolution position monitor. One of the wire scanners was used as a position jitter detector [5].

4.1 Jitter measurement with wire scanner

The wire scanner which have 10 μm diameter tungsten wire was used for the jitter measurement. Scattered gamma rays from the wire are detected by air Cherenkov detector with photo multiplier. Before orbit measurement we measured horizontal beam profile and set the wire at the position which is middle of the slope of the profile. The distribution of detected gamma rays is converted to the distribution of the position with beam profile. Horizontal beam size was around 100 μm in these measurements.

4.2 Optics tuning method

Changing β function at the second kicker, a minimum position jitter was surveyed. However, the condition of jitter compensation was different in each optics setting because dispersion and orbit was corrected in each setting independently. Then the position jitter caused by kick angle variation was compared by normalizing each condition with β function 2.5m at the wire and phase advance 1.5 π from the second kicker. The result is summarized in Table 3 .

With these values a β function of maximum jitter reduction and kick angle jitter are estimated. Assuming model optics and kick angle ratio k, kick angle variation

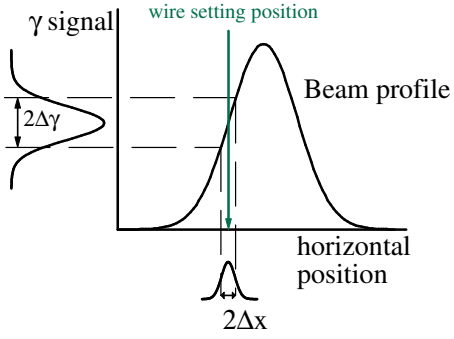

Figure 3: Beam jitter measurement using wire scanner

Table 3: Result of optics tuning

β function 2nd Kicker	estimated σ_{kicker}	β function wire	phase advance
5.0 [m]	11.4 [μm]	2.47 [m]	1.507 [π]
6.0	11.0	2.49	1.501
8.0	10.9	2.65	1.492
10.0	11.4	2.59	1.482
12.0	12.9	1.81	1.501

will be $\Delta\theta_1 = k\Delta\theta_2$, horizontal displacement is written by $\Delta x_{kicker} = R_{12}(1, wire)\Delta\theta_1 + R_{12}(2, wire)\Delta\theta_2 = \sqrt{\beta_{wire}}\Delta\theta_1(\sqrt{\beta_1} - k\sqrt{\beta_2})$.

By fitting

$$\sigma_{estimated} = \sqrt{\sigma_{kicker}^2 + \sigma_{resolution}^2}$$

at each optics setting,

$$\begin{aligned} k &= 0.833 \\ \Delta\theta_1 &= 6.7\mu rad \\ \sigma_{resolution} &= 10.7\mu m \end{aligned}$$

were obtained.

Measured β function at the first kicker was 4.95m, so β function at the second kicker for maximum jitter reduction was estimated to be 7.13m. The estimated resolution 10.7μm is included monitor resolution and incoming position and angle jitter. The resolution of this position monitor using wire is estimated about 1μm, then it seemed that the beam orbit of damping ring had fluctuation in these measurements. The kick angle ratio 0.833 is not explained by the difference of the cable length between the two kickers (9.4m). It seemed that the difference of ceramic coating between the two kickers caused the much difference of the field strength.

5 CONCLUSION

The performance of the double kicker system was studied with measurement of horizontal orbit jitter in single bunch mode. The system has the jitter less than the resolution of

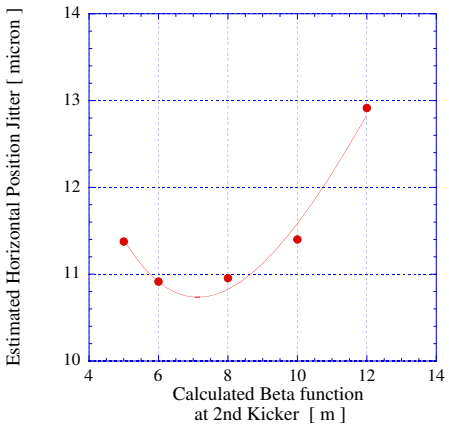

Figure 4: Position jitter dependence on β function at the second kicker

BPM in small kick variation. The survey of the maximum reduction optics changing β function at the second kicker was performed with wire scanner. The β function which gave a minimum position jitter was found. Estimated β function for it was 7.13m and this corresponded to the kick angle ratio of the two kickers 0.833.

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