DEVELOPMENT OF STRIP-LINE KICKER SYSTEM FOR ILC DAMPING RING *

T. Naito#, J. Urakawa, K. Kubo, M. Kuriki, N. Terunuma, H. Hayano, KEK, Tsukuba, Japan

Abstract

The performance of a kicker system for the International Linear Collider(ILC) is one of the key technologies for determining the circumference and the train structure of a damping ring(DR). The parameters are being discussed as the baseline configuration design for the ILC. The bunch trains in the linac consist of 2820(or 5640) bunches with 330(or 165) ns spacing and the repetition rate is 5Hz. The bunch spacing in the DR is 6(or 3) ns. The kicker is required to have fast rise and fall times of less than 6(or 3) ns and a repetition rate of 3(or 6) MHz. The development work of the kicker system using multiple strip-lines is carried out at KEK-ATF. The beam test result of the single unit is presented. The design of the beam extraction from ATF-DR to the extraction line is described.

INTRODUCTION

Damping rings (DR) play a significant role in producing very low emittance beams in the International Linear Collider(ILC). A long bunch train, comprising 2820(or 5640) bunches with a bunch spacing 330(or 165) ns, is accelerated in the ILC. The length of the bunch train is greater than 200km. The bunch spacing is required to be compressed into and has to be decompressed from the DR. The bunch spacing in DR is 3(or 6) ns and the circumference of the DR is 6.7km in the base line design [1].

For the injection and extraction of the beams, kickers require the bunch-by-bunch beam manipulation. For the 5640-bunch operation, the kick field is required to have a very fast pulse waveform, the rise and fall times are required to be less than 3 ns, and the required repetition rate is 6 MHz. The required kicker parameters in the base line design are shown in Table 1. It is impossible to realize these parameters by extending conventional kicker technologies, such as a ferrite pulsed magnet powered by a thyratron switching pulse power supply.

The proposed strip-line kicker system, which consists of multiple units of strip-line electrodes and very fast pulse power supplies, has been designed. The beam test of a single unit of the strip-line kicker system was carried out at the Accelerator Test Facility (ATF) in KEK. A waveform compensator for improving the rise and fall times of the kick field was also tested. This paper describes the experimental results. We also describe the design of the beam extraction from ATF-DR to the extraction line as a demonstration of the strip-line kicker system performance.

*Work supported by .US/Japan Sci.and Tech. Collaboration program.
#takasshi.naito@kek.jp

Table 1. Parameters of the ILC DR kicker.

Kick angle	0.6 mrad
β_x at kicker	50 m
Repetition rate of the burst	3 MHz for 2820 bunches 6 MHz for 5640 bunches
Macro-pulse length	1 ms
Repetition rate of the macro-pulse	5 Hz
Rise and fall time	<3.08 ns for electron ring and 5640 bunches <6.154 ns for positron ring and 5640 bunches
Peak kick stability	0.07%
Residual kick	<0.42 μrad

STRIP-LINE KICKER

When a charged particle travels a direction opposite to that of an electro-magnetic field, the particle experiences a transverse kick due to the electromagnetic field [2]. When a pulse voltage is applied to the strip line, this electromagnetic field is transmitted in the strip-line electrode almost at the speed of light. The relativistic charged particle travels at the speed of light in the opposite direction. It experiences the electromagnetic field with a rise time of 2L/c, where L is the strip-line length and c is the speed of light. This implies that if the pulse has the perfectly sharp rise of a step function, and is applied to a 30 cm long strip-line, the peak field of the pulse is obtained at 2 ns after the leading edge of the pulse arrives at the strip-line. This is equivalent to a pulse rise time of 2 ns. If the pulse has a rise time like a trapezoidal pulse, the kick field is obtained by the integration of the pulse voltage,

$$\theta(t) \propto \int_t^{t+2L/c} V(t)dt, \tag{1}$$

where, θ is a kick angle and V(t) is pulse voltage. To achieve a 3 ns rise time of the field in the case of a 30 cm strip-line, the rise time of the applied pulse voltage must

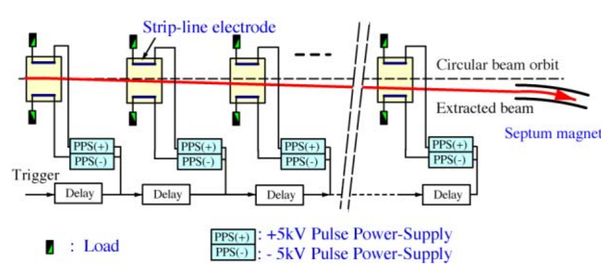

Figure 1: Schematic layout of strip-line kicker system

be less than 1 ns. To get the required kick angle while keeping the rise time of the kick field for the ILC parameters, multi-units of the strip-line are required. The schematic layout of the strip-line kicker system is shown in Figure 1. The strip-line length of each unit is L, the distance between the electrodes is d, and the applied pulse voltage for both electrodes is V. The kick angle $\Delta\theta$, is approximately given by

$$\Delta\theta = 2g\frac{eV}{E}\frac{L}{d}, \tag{2}$$

where E is the beam energy and g is the geometry factor, determined by the shape of the electrode. The geometry factor g is given by

$$g = tanh\left(\frac{\pi\omega}{2d}\right). \tag{3}$$

where ω is the strip-line width.

Each author should submit all of the source files (text and figures), the postscript file and a hard copy version of the paper. This will allow the editors to reconstruct the paper in case of processing difficulties and compare the version produced for publication with the hard copy.

BEAM TEST AT KEK-ATF

A commercially available pulse power supply was used as the pulse source for the strip-line kicker. A pulse power supply, model FPG5-3000M fabricated by FID Technology Ltd., uses a drift step recovery diode technology, which almost meets the specifications required for ILC kickers. The main parameters are as follow, peak voltage: 5kV, rise time: 1.2ns, pulse width: 2ns, and repetition rate: 3MHz. The waveform of the FPG5-3000M is shown in Figure 2. Pulse power supplies are also being developed at DESY [3] and LLNL [4]; their rise time specifications are 2.5 ns and 4 ns, respectively.

Single strip-line experiment

The beam kick test was carried out in ATF-DR by using a single unit of the strip-line and a FPG5-3000M pulse power supply. The strip-line electrode is 32 cm

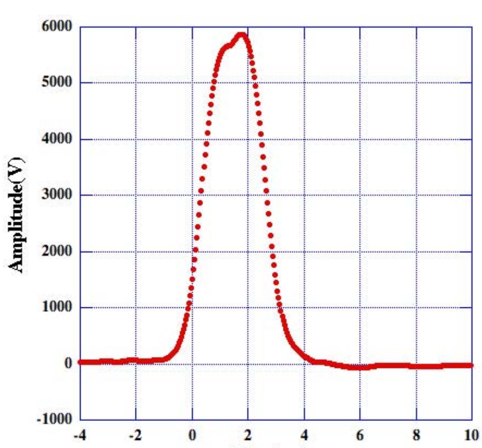

Figure 2: Waveform of the FPG5-3000M output

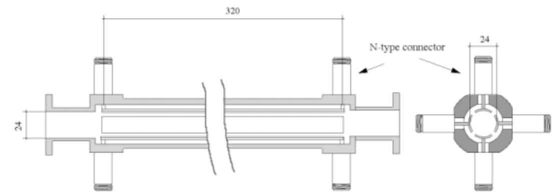

Figure 3: Strip-line electrode used for the beam test

long and 24 mm in diameter. Its structure is shown in Figure 3. The pulse power supply is connected to one of the electrodes, the other electrodes are terminated to 50 ohm. The electrode was originally designed to perform the tune measurements in the horizontal and vertical

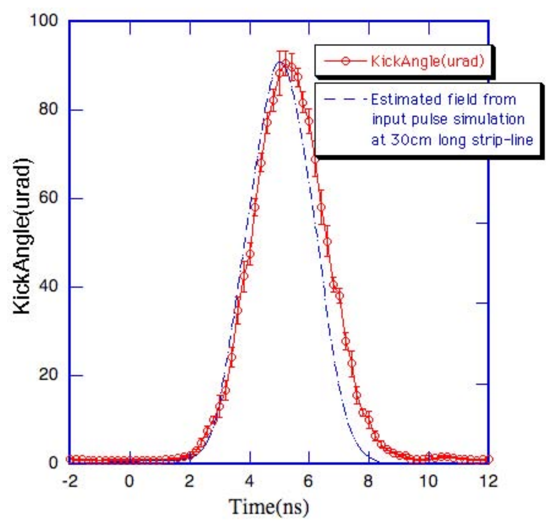

Figure 4: Beam kick profile as a function of the kick pulse timing

directions, rather than function as a kicker. In the 1.3-GeV DR, the kick effect of the single unit resulted in a 100 μrad kick angle of the beam oscillation. A turn-by-turn beam position monitor was used to measure the kick angle of the strip-line kicker. The absolute value of the kick angle was evaluated from the amplitude of the betatron oscillation.

Figure 4 shows the beam kick profile as a function of the kick pulse timing. The solid and dashed lines represent the measured and calculated fields, respectively, when the input pulse shown in Figure 2 is applied to the 32 cm long strip-line. The measured rise and fall times are 3.2ns and 4.0ns, respectively. The calculated rise and fall times are both 2.8ns. The discrepancy between the measurement and the calculation is suspected to be caused due to the mismatching of the strip-line makes the deterioration of the rise and fall times. The impedance of the strip-line is 50.9 ohm and the impedances of both sides of the feed-through are 103 ohm and 76 ohm, respectively.

Waveform Compensator

In order to realize rise and fall times of less than 3 ns of the kick field, a waveform compensator consisting of two

1-4244-0917-9/07/$25.00 ©2007 IEEE

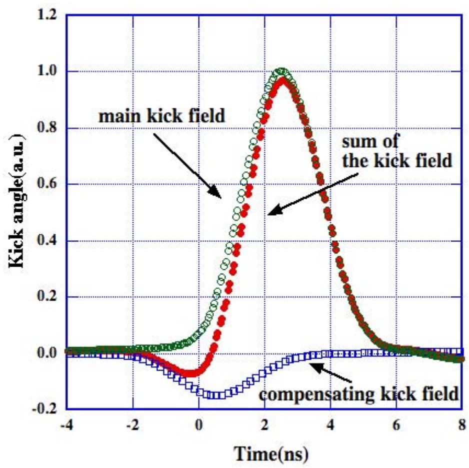

Figure 5: Simulated kick field with waveform compensator

strip-line kicker units was developed. The combination of the main kick field on one strip-line and a compensating kick field on the other strip-line results in a bipolar kick field. By adjusting the amplitude and timing of the compensating kick field, the rise time of the resultant kick field can be reduced. Figure 5 shows the simulated kick field of the waveform compensator. The open circles represent the main kick field with relative amplitude 1 in the positive direction. The open squares represent the compensating kick field with relative amplitude 0.15 in the negative direction. The timing is slightly shifted towards an earlier time from the main kick. The sum of the two kick fields is represented as filled circles. The improvement of the rise time can be seen in the resultant kick field as compared to the main kick field.

A similar measurement using the single strip-line experiment was carried with the waveform compensator. The measurement result, the absolute value of the kick angle as a function of time, is shown in Figure 6. The rise time was improved from 3.2ns to 2.2ns, these values agree with those of the simulation. The zero cross point can be adjusted to arbitrary timing, i.e. the timing of the previous bunch. The fall time was improved from 4.0ns to 2.4ns by adjusting the compensation pulse timing.

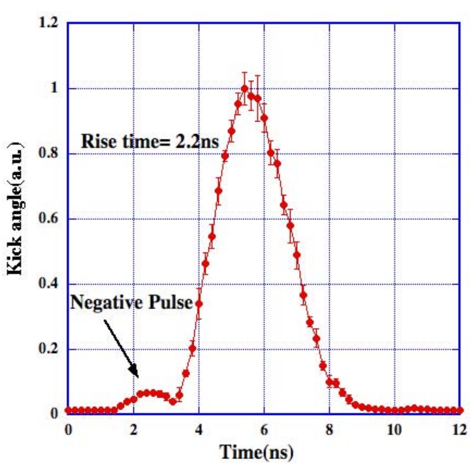

Figure 6: Beam kick profile with waveform compensator

BEAM EXTRACION BY USING STRIP-LINE KICKER

The beam extraction by using the strip-line kicker was designed from ATF-DR to the extraction line. The ATF-DR can store up to 60bunches of multi-bunch with 2.8ns bunch spacing. The present kicker of the ATF-DR uses a pulse magnet and a thyratron switch pulse power supply, which produces a kick angle of 4.5 mrad for the beam extraction. All the beams are extracted at the same time with the same bunch spacing in the case of the present kicker. A difficulty in the installation of the strip-line kicker is the lack of sufficient space for the installation of the strip-line electrodes in order to obtain the same kick angle. We designed a beam extraction orbit by using pulse bump magnets and an auxiliary septum magnet. The bump orbit is gradually exited after the beam emittance is damped. The beams are extracted bunch-by-bunch with a 154ns bunch spacing, when the pulse power supplies are driven with 6.5MHz. The layout is shown in Figure 7. In

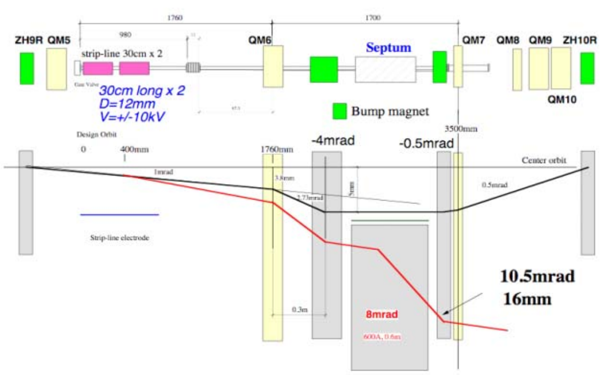

Figure 7: Layout of the beam extraction section for the strip-line kicker

this design, two strip-lines of 30cm long with 12mm electrode distance operated by +/-10kV pulses are used.

ACKNOWLEGEMENT

The authors would like to express their gratitude to Professors Y.Kamiya and K.Yokoya for their encouragement.

REFERENCES

[1] A. Wolski et al., “Configuration Studies and Recommendations for the ILC Damping Ring”, LBNL-59449, Cockroft-06-04, Feb 2006
[2] G.Lambertson, “Dynamic Devices – Pickup and kickers”, AIP Conf. Proc. 153, p.1414(1987)
[3] W. Decking, “TESLA Damping Ring Kicker Work Status”, talk at DR2003 http://www.astec.ac.uk/conf/dampingring/
[4] E. Cook, “Solid-State Inductive Adders for Fast Kicker “, talk at RPIA2006 http://conference.kek.jp/rpia2006/