DESIGN OF THE BEAM EXTRACTION BY USING STRIP-LINE KICKER AT KEK-ATF*

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Abstract

The developing work of the strip-line kicker system for International linear collider(ILC) is carrying out at KEK. To confirm the performance of the kicker system, the beam extraction test by using the strip-line kicker at KEK-ATF is proposed. The multi-bunch beam, which has 5.6ns bunch spacing in the damping ring, is extracted from the damping ring to the extraction line with 154ns (or 308ns) duration. The scheme is the same as the kicker of the ILC except for the number of bunches. The bump orbit and the auxiliary septum magnet are used with the strip-line kicker for the geometrical restriction. The detail of the hardware design and the basic performance of each component are presented in this paper.

INTRODUCTION

The International Linear collider(ILC) is a 200-500GeV center of mass high-luminosity electron-positron collider. Damping rings (DRs) have significant role to realize high-luminosity. The beam of the ILC is a long bunch train, comprising 2820(or 5640) bunches. The bunch spacing is 165ns (or 330ns) upstream of the DR and it is compressed to 3(or 6) ns in the DR and is decompressed to 165ns (or 330ns) again at the downstream of the DR. The circumference of the DR is 6.7km in the base-line design [1]. The injection/extraction kickers act as the bunch-by-bunch beam manipulator to compress the bunch spacing into the DR and to decompress the bunch spacing from the DR. The kicker requires high repetition frequency, 3(or 6) MHz, and very fast rise/fall time of the kick field, 6(or 3) ns. A system using multi-units of strip-line kicker is the most promising candidate to realize the parameters. Authors already tested the single-unit of the strip-line kicker by using semiconductor high voltage pulse source and confirmed the fast rise/fall time of the beam kick field. [2][3] The test was the beam kick profile measurement by exciting the beam in the ring changing the kicker pulse timing. The multi-unit and the burst operation of the kicker need to be checked.

To confirm the performance of the strip-line kicker system, the beam extraction test is planed by using KEK accelerator test facility (ATF). The present kicker system of the ATF damping ring (DR) uses a pulse magnet, which produce 4.6mrad of the kick angle to the beam and the length of the pulse magnet is 60 cm long. This kicker can't extract the beam bunch by bunch. The strip-line kicker will be able to extract many bunches with about 154ns bunch spacing. One of the problems, to replace the pulse magnet kicker to the strip-line kicker, is the geometrical restriction. There is not enough space to install many strip-lines to produce same kick angle as the pulse magnet, so that local bump magnets and an auxiliary septum magnet are required to make the beam extraction trajectory.

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BEAM EXTRACTION SCHEME BY USING STRP-LINE KICKER

Figure 1 shows the bunch spacing in the DR and the extraction line using the strip-line kicker. The stored beams in the DR are 3 trains, 154ns apart for each train (spacing between train heads), one train consists of 10 bunches with 5.6ns bunch spacing, 30 bunches total. The revolution time is 462ns. The strip-line kicker kicks out bunch by bunch from the tails of the trains with 154ns or 148.4ns interval.

The strip-line kicker requires less than 5.6ns of rise time of the kick field and 30 pulses with 6MHz repetition frequency. The beam extraction scheme is the same as the kicker of the ILC except for the number of bunches.

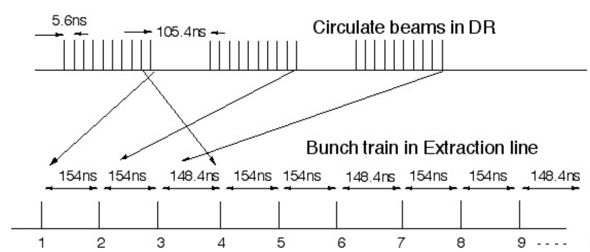

Figure 1: Bunch spacing in DR and in extraction line.

PERFORMANCE OF THE STRIP-LINE KICKER

One of the key technologies is a high voltage pulser to drive the strip-line. The pulser requires 5kV of the peak voltage, 1ns of the rise/fall time, 3MHz of the burst pulse at 1ms duration, 5Hz of operation and small time jitter to realize the ILC parameters. It is very difficult to make such a high speed switching, a high voltage and a high frequency by using ordinary switching devices such as thyratron. FPG5-3000M (FID Technology, Ltd.) by using semiconductor technology meets these parameters. The beam kick test using the single unit of the strip-line kicker was carried out at DR by measuring the betatron oscillation amplitude in the ring. [2][3] A pair of FPG5-3000M pulsers is used to provide positive and negative 5kV pulses at same timing. The strip-line electrode is a

30cm long, 12mm gap distance and 9mm electrode width. The measured beam kick profile is shown in Figure 2. The measured rise/fall time of the beam kick field was 3ns each, which meets ILC requirements. The measured peak kick angle was 0.44mrad.

The FPG5-3000M showed good characteristics for the rise/fall time. However, the kick angle is inadequate to use as the beam extraction kicker by replacing the existing pulse magnet. We use FPG10-6000KN, 10kV pulser, for the beam extraction. The parameters of the FPG10-6000KN are 10kV of the peak voltage, 1ns of the rise time, 3ns of pulse width (FWHM), 70 pulses with 6MHz of the burst pulses, 1.5Hz of operation and small time jitter. The parameters are optimized for this experiment.

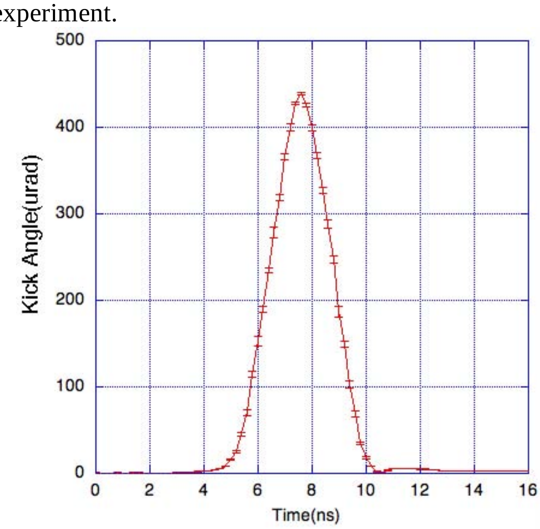

Figure 2: Beam kick profile by using a pair of FPG5-3000M and a 30cm long strip-line kicker.

Figure 3 shows the waveform of the FPG10-6000KN output and the calculation of the kick angle applying the pulse to the strip-line in the case of 30, 45, 60 and 75cm long, respectively. The kick angle is the result when the pulse is applied to the single side of the strip-line. The pulse width of the FPG10-6000KN is not long enough compare to the filling time of the strip-line, especially for the longer strip-line length, so that the calculated kick angle is not proportional to the strip-line length. In the case of 60cm long strip-line, the rise time is less than 5ns and the kick angle is over 0.6mrad. With two units of 60cm long strip-lines applying high voltage pulse to both sides of he strip-lines, the total kick angle is 2.4mrad.

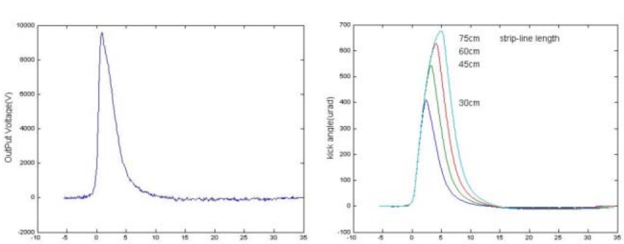

Figure 3: Waveform of the FPG10-6000KN output and calculation of the kick angle in the case of 30, 45, 60 and 75cm long strip-lines.

DESIGN OF EACH COMPORNENT FOR THE STRIP-LINE KICKER SYSTEM

Figure 4 shows the beam extraction trajectory in the case of the pulse magnet kicker (upper) and the strip-line kicker with the bump orbit and the auxiliary septum (lower). The pulse magnet produces 4.6mrad of the kick angle. The extracted beam center has 25mm offset and 0mrad angle at the entrance of the existing septum magnet.

Two units of strip-line kicker produce about 2mrad of the kick angle. There is no space to install additional strip-line. To make more than 20mm offset from of the center orbit at the entrance of the existing septum magnet, steering magnets and an auxiliary septum magnet are used. The steering magnets make a local bump orbit with 4mm orbit deviation at the entrance of the auxiliary septum magnet. The auxiliary septum magnet adds 8mrad of the bending angle to the kicked beam by the strip-line kicker. The extracted beam has 20mm offset and 4mrad angle at the entrance of the existing septum. The other bunches, which are not kicked by the strip-line kickers, go though the bump orbit and circulate in the DR.

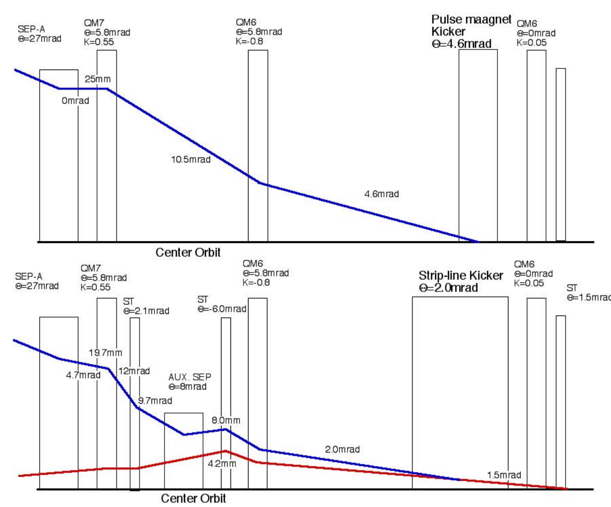

Figure 4: Trajectory of the beam extraction – Pulse magnet kicker (upper), strip-line kicker with bump orbit and auxiliary septum (lower).

Aperture for the Injection Beam

The horizontal aperture is limited for the gap width of the strip-line electrode. When the injection beam has 1x10-6 of the horizontal emitance and 1% of the energy spread, the beam size at the strip-line location is about 2mm. The 12mm gap of the strip-line corresponds to 6σ of the injection beam. Figure 5 shows the calculated beam size for the injection beam.

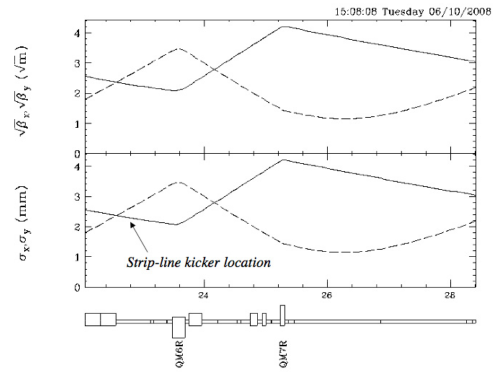

Figure 5: Calculation of the injection beam size.

Local Bump Orbit Design

To keep the aperture for the injection beam, the bump orbit is gradually exited after the beam emittance is damped. All of the bump magnets need to be excited periodically. The local bump starts after several damping time. The beam is kicked out at the flattop of the bump. The bump is turned off after all bunches are kicked out.

The bump orbit requires 4mm of bump height at the entrance of the auxiliary septum, small displacement at the existing septum location and the closed dispersion function. Seven steering magnets are used for the bump. The design orbit is shown in figure 6.

The bump orbit was already tested. The test confirmed the orbit change without any beam loss for the injection beam and without any beam blow up for the vertical emittance for the damped beam.

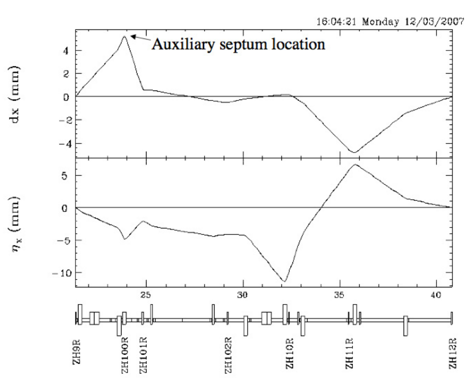

Figure 6: Calculated bump orbit and the dispersion function.

Auxiliary Septum Design

The auxiliary septum requires a thin separator electrode, which delivers the kicked beam to the extraction line. The design based on the design of PEP-II septum. [4] The main parameters of the septum are as follow, magnet length: 60cm, magnet gap: 10mm, bending field: 0.1T, current: 800A and separator width: 1.6mm. The thin separator will not be able to use the hollow conductor, so that the cooling channels, made by stainless steel, will be welded at the upper side and the lower side of the separator. Figure 7 shows the cross section of the designed septum used by OPERA. [5] The auxiliary septum is under fabrication.

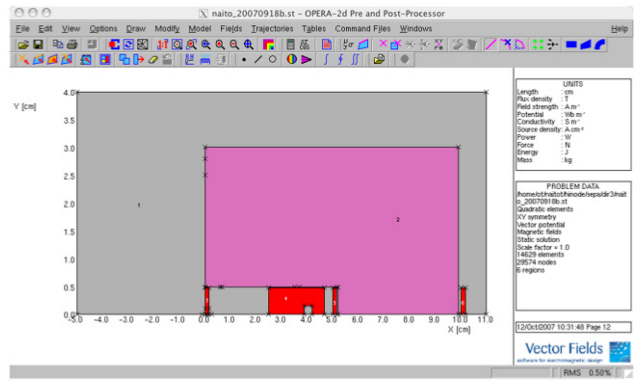

Figure 7: Cross section of the designed auxiliary septum.

SUMMARY

The strip-line kicker system for the beam extraction from the DR to the extraction line is designed at KEK-ATF. To make the trajectory for the beam extraction, the strip-line kicker operates with the local bump magnets and the auxiliary septum magnet. The orbit design and each component test are carried out, successfully.

ACKNOWLEGEMENT

The authors would like to express their gratitude to Professors Y.Kamiya and K.Yokoya for their encouragement and support. The authors would like to thank Drs. Tawada and Nakayama for useful advice on the design of the auxiliary septum.

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