# BEAM EXTRACTION USING STRIP-LINE KICKER AT KEK-ATF *

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*Abstract*

The kicker of the damping ring for the International linear collider (ILC) requires fast rise/fall times (3 or 6 ns) and high repetition rate(3 MHz). A multiple strip-line kicker system is being developed to realize the specifications at KEK [1]. We present the preparation for the beam test of the strip-line kicker at KEK-ATF [2]. The multi-bunch beams in the damping ring, which have 5.6 ns bunch spacing, are extracted bunch-by-bunch with 308 ns duration. Two units of the strip-line kicker are used to extract the beam. The scheme of the beam extraction is the same as the kicker of the ILC except for the number of bunches. A bump orbit and an auxiliary septum magnet are used with the kicker to overcome the geometrical restriction.

## INTRODUCTION

The International Linear Collider(ILC) is an electron-positron collider with a 200-500 GeV center of mass energy. The damping rings(DRs) for the electron and the positron beam have significant role in realization the high-luminosity at the collision point. The beam of the ILC has a long bunch train, composed to 2625 (or 5534) bunches. The bunch spacing is 330ns (or 165ns) upstream of the DR and is compressed of 6 (or 3) ns in the DR and again decompressed to 330 ns (or 165 ns) at the downstream of the DR. The circumference of the DR is 6.7 km in the base-line design [1]. The injection/extraction kickers act as the bunch-by-bunch beam manipulator to compress and decompress the bunch spacing into/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 kickers is the most promising candidate to realize the parameters. The authors previously 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 measurement of the beam kick profile was done exciting the beam with the strip-line kicker and changing the kicker pulse timing. However, the multi-unit operation and burst operation of the kicker need to be verified.

To confirm the performance of the strip-line kicker system, the beam extraction test was planned by using KEK accelerator test facility (ATF). The present kicker system of the ATF-DR uses a pulse magnet, which gives 4.6mrad kick angle to the beam. The length of the pulse magnet is 60 cm long. This kicker is driven by a thyraton switch, which does not have the capability of the high frequency operation and the fast rise/fall time. One of the problems, in replacing the pulse magnet kicker with the strip-line kicker, is the geometrical restriction. There is not enough space to install many strip-lines to produce the same kick angle as the pulse magnet, so that local bump orbit and an auxiliary septum magnet are required to create the beam extraction trajectory.

## DESIGN OF ATF STRIP-LINE KICKER SYSTEM FOR ATF

Figure 1 shows the comparison of the beam extraction trajectories of the present pulse magnet kicker (upper figure) and the strip-line kicker with the bump orbit and the auxiliary septum (lower figure).

The pulse magnet produces 4.6 mrad kick angle. The extracted beam has 25 mm offset and 0mrad angle at the entrance of the existing septum magnet. Two units of strip-line kicker produce a total of 2 mrad kick angle. There is no space to install additional strip-lines in the DR. To make more than 20 mm offset from the center orbit at the entrance of the existing septum magnet, local bump orbit and an auxiliary septum magnet are needed. The steering magnets make a local bump orbit with 4 mm orbit deviation at the entrance of the auxiliary septum magnet. The auxiliary septum magnet gives 8 mrad bend angle to the kicked beam. The extracted beam has 20 mm offset and 4 mrad angle at the entrance of the existing septum. The residual bunches, which are not kicked by the strip-line kickers, go though the bump orbit and circulate in the DR.

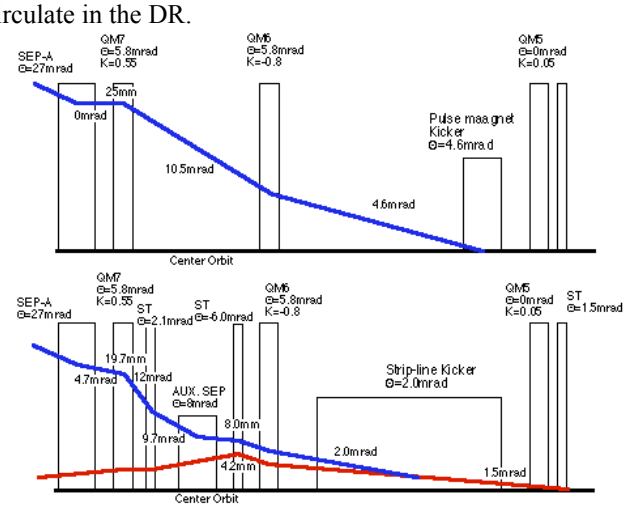


Figure 1: Trajectory of the beam extraction – Pulse magnet kicker (upper), strip-line kicker with bump orbit and auxiliary septum (lower). The red line in the lower figure is the local bump orbit.

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Figure 2 shows the schematic layout of the strip-line kicker for ATF. The strip-line electrodes are 60 cm long with a gap spacing of 12 mm. The required aperture for the injected beam limits the gap distance. Assuming that the injected beam has $1\text{x}10^{-6}$m horizontal emittance and 1% energy spread, the gap of he electrode correspond to 6σ of the beam size. Positive and negative pulses are applied to both electrodes with the same timing to make maximum kick field. The kick angle Δθ is given by

$$\Delta\theta = 2g\frac{eV}{E}\frac{L}{d} \qquad (1)$$

where E is the beam energy, V is applied voltage, L is the length of the strip-line, d is the gap of the strip-line and g is the geometry factor given by following equation,

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

where ω is the strip-line width.

The pulse timing for two units have to be adjusted to the beam for giving maximum kick. The strip-line kicker requires less than 5.6 ns of rise time of the kick field and 30 pulses with 308 ns duration. The beam extraction scheme is the same as the kicker of the ILC except for the number of bunches.

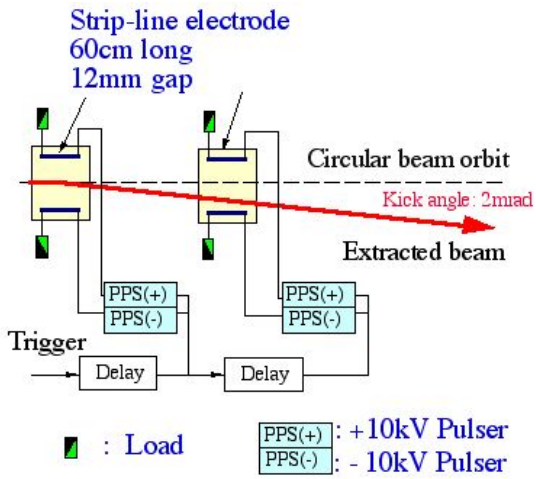


Figure 2: schematic layout of the strip-line kicker.

## PERFORMANCE OF THE STRIP-LINE KICKER

One of the key technologies is a high voltage pulser to drive the strip-line. For the ATF beam kicker, the pulser needs to have +/-10kV peak voltage, 1ns of the rise time, 3MHz of the burst pulse with 30 pulses and small timing jitter. It is impossible to make such a high speed switching with the high voltage and the frequency by using ordinary switching devices such as thyratron. FPG10-6000KN (FID Technology, Ltd.) satisfies the requirement by using the drift step recovery diode technology. The waveform of the FPG10-6000KN is shown in Figure 3a. The beam kick test using single unit of the strip-line kicker was carried out at the ATF DR by measuring the betatron oscillation amplitude in the DR [2][3]. A pair of FPG10-6000KN pulsers is used to provide +/-10kV pulses with the same timing. In this experiment, the strip-line electrode is 30 cm long, 12 mm gap distance and 9 mm electrode width. The measured beam kick profile is shown in Fig. 3b. The measured rise time and kick angle were 3 ns and 0.7 mrad, respectively.

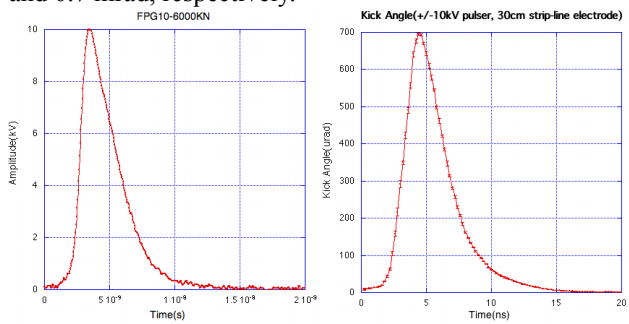


Figure 3a(left): Waveform of the FPG10-6000KN; Figure 3b(right): Beam kick profile using a pair of FPG10-6000KN and a 30 cm long strip-line kicker.

Figure 4 shows the calculation of the kick angle, assuming the pulse of the FPG10-6000KN is applied to the single side of the strip-line with length of 30, 45, 60 and 75 cm long. The pulse width of the FPG10-6000KN is not sufficiently long compare with the filling time of the strip-line, especially for the longer strip-line length. Therefore the calculated kick angle is not proportional to the strip-line length. In the case of long strip-line, the rise time is less than 5 ns and the kick angle is >0.6mrad. When two units of 60 cm long strip-lines with +/-10kV pulser are used, the produced kick angle is 2.4 mrad.

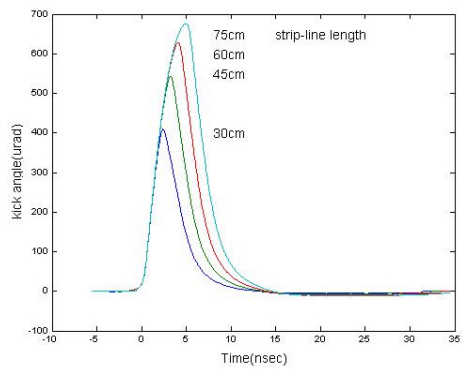


Figure 4: Calculation of the kick angle in the case of 30, 45, 60 and 75cm long strip-lines.

## FABRICATION OF THE COMPORNENTS

### *Strip-line Electrode*

Figure 5 shows the picture of the strip-line electrode. The shape of the electrode is designed by using POISSON. The impedance of the electrode is maintained at 50 Ω from the input connector to the output connector in the design. The shape of the electrode is designed for minimizes the electric field to avoid the discharge. HN-type commercially available feed-through is used for the

input/output connectors. The pulse output of FPG10-6000KN could be applied without any discharge.

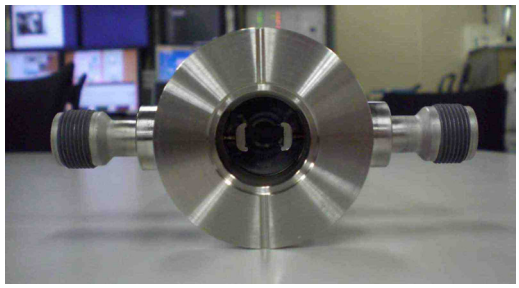

Figure 5: Picture of the strip-line electrode.

### *Auxiliary Septum Magnet*

The design of the auxiliary septum was based on the PEP-II septum [4]. The main parameters of the septum are showed in Table 1.

Table 1: Parameters of the Auxiliary Septum

| | |
|---|---|
| Magnet length | 60 cm |
| Magnet gap | 10 mm |
| Bending field | 0.06 T |
| Magnet current | 600 A |
| Separator width | 1.6 mm |

A hollow conductor cannot be used as a thin separator, because the cooling channels need the space inside of the separator. The cooling channels, made of stainless steel, are welded at the upper and lower sides of the separator. The dimension of the septum was designed by OPERA [5]. Figure 6 shows the cross section of the designed septum. The fabricated auxiliary septum is also shown in Fig. 7. The auxiliary septum is installed in the vacuum chamber and the power cables and cooling channels are connected through the ceramic feed-through. The magnetic field was checked up to 600 A without any heat problem.

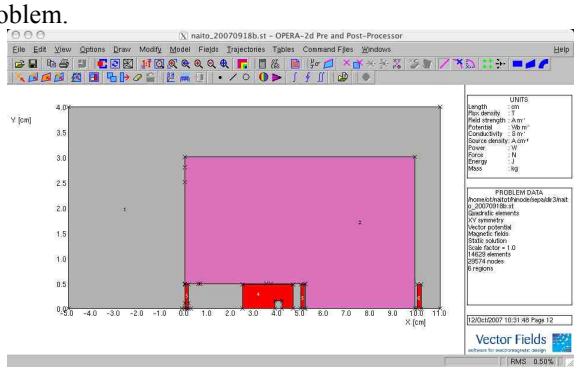


Figure 6: Cross section of the designed auxiliary septum.

## BEAM TEST

We tried the beam extraction with the strip-line kicker. The behavior of the bump orbit and the required current operation of the auxiliary septum were confirmed. Unfortunately, the pulser had trouble during the beam test. We suspect the semiconductor devices had radiation damage, because they were not designed to withstand strong radiation. The pulser was located very close to the strip-line kicker and the location of the kicker was in a high radiation level during the beam operation.

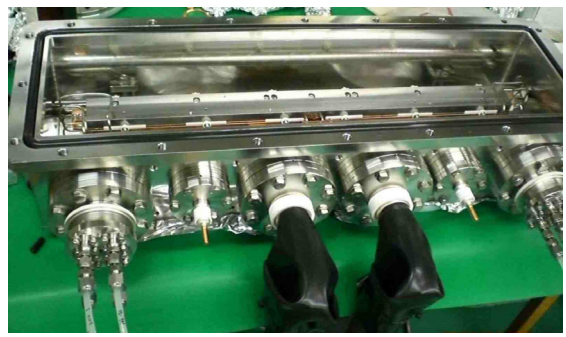

Figure 7: Picture of the auxiliary septum.

## SUMMARY

The preparation of the strip-line kicker for beam extraction from the DR to the extraction was satisfactorily done. Each component for the beam extraction was fabricated and its performance was checked. The beam test was postponed for the pulser trouble. The beam test will be resumed after modified the location of the pulsers to the out of the shielding to avoid radiation damage.

## ACKNOWLEGEMENT

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