MULTI-BUNCH BEAM EXTRACTION USING STRIP-LINE KICKER AT KEK-ATF *

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Abstract

The kicker of the International Linear Collider(ILC) has very special role, it injects/extracts the beam to/from the damping ring(DR). The long bunch train(1320 - 5120 bunches), which has a bunch spacing of 189 - 480ns, is compressed to 3ns(or 6ns) into the DR. The bunch train is then decompressed again from the DR. The kicker acts as the bunch-by-bunch beam manipulator to compress and decompress the bunch spacing into/from the DR. It requires a fast rise/fall time (3 or 6ns) and a high repetition rate (6 or 3MHz). A multiple strip-line kicker system is a most promising candidate to realize the specification of the ILC reference design. The beam extraction experiment using the proto-type of the strip-line kicker has been carried out at KEK-ATF. The stored multi-bunch beam in the DR was extracted successfully with different bunch spacing. The detail of the experiment and the results are reported.

INTRODUCTION

The International Linear Collider(ILC) is an electron-positron collider with a 200-500GeV 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 is a long bunch train(1320 - 5120 bunches). The bunch spacing in the linacs are 189ns - 480ns and the bunch spacing in the DRs are 3ns or 6ns. 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 and decompress the bunch spacing into/from the DR. The kicker requires high repetition frequency, 6(or 3) MHz, and very fast rise/fall time of the kick field, 3(or 6) ns. A system using multi-units of strip-line kicker is the most promising candidate to realize the parameters. The single-unit of the strip-line kicker using semiconductor high voltage pulse source was already tested and the rise/fall time of the beam kick field was measured. [2][3] The measurement of the beam kick profile was done by exciting the beam with the strip-line kicker and changing the kicker pulse timing.

The multi-unit operation and the burst operation of the kicker are required to confirm the performance of the strip-line kicker system. The beam extraction test with a prototype fast kicker was carried out at KEK-ATF DR to the ATF2 extraction line. [4] The characteristics of the extracted beam were measured with the beam position monitors at the extraction line.

EXPERIMENTAL SETUP

Two units of strip-line kickers were installed, temporarily replacing the conventional extraction kicker, which has been put offline. A successful beam extraction was demonstrated in the beam operation. Figure 1 shows the picture of the strip-line kickers beside the replaced conventional extraction kicker.

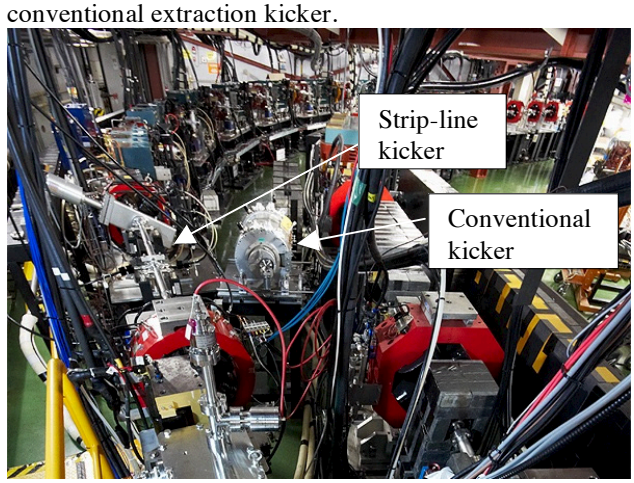

Figure 1 Two units of strip-line kickers in ATF

The length of the strip-lines was 60cm and the gaps of the electrodes were 9mm and 11mm, respectively. Two pairs of 10kV pulsers were used to drive the strip-lines. The strip-line kicker produced a 3mrad kick angle for the 1.3GeV beam. The pulse bump orbit and the auxiliary septum magnet were used with the strip-line kicker due to geometrical restriction. Figure 2 shows the beam trajectory with the pulse bump and the kicked beam orbits.

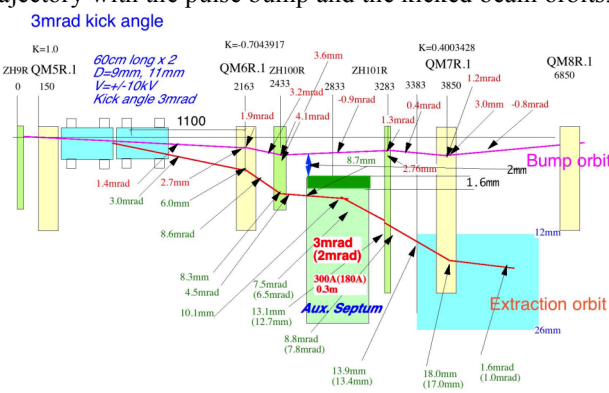

Figure 2. Extraction Orbit

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KICK FIELD ESTIMATION

The pulser(model FPG10-3000KN fabricated by FID Co. Ltd.) has a good performance. The main parameters are peak amplitude of 10kV, rise time of 1.5ns and repetition rate of 3.3MHz(burst). Figure 3 shows the pulse waveform of the pulser(left) and the estimated kick field(right) when a 60cm long and 9mm gap distance strip-line electrode is used. The rise time of the kick field is less than 5ns. The estimated kick angle is 0.9mrad, which does not take into account the cable loss and the reflection coming from the mismatching at the strip-line. It will be about 10% lower than the estimated value. When two units of 60cm long strip-lines with +/-10kV pulser are used, the resulting kick angle is 3mrad.

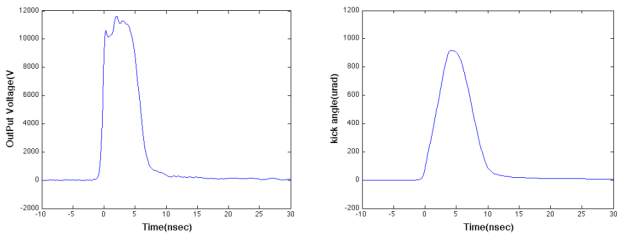

Figure 3: Pulse waveform of the pulser(left) and the estimated kick field(right)

MULTI-BUNCH BEAM EXTRACTION

Figure 4 shows the bunch spacing in the DR and the extraction line. The stored beams in the DR are 3 trains, spaced 154ns apart for each train with each train consisting of 10 bunches with 5.6ns bunch spacing, for a total 30 bunches. The revolution time is 462ns. The strip-line kicker kicks out bunch by bunch from the last bunch of each train with 308ns(302.4ns for every three pulses) interval.

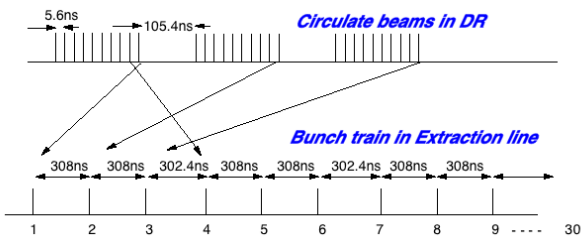

Figure 4: Bunch spacing in DR and in Extraction line

Figure 5 shows the extracted multi-bunch beam signal. The blue line shows the waveform of the current monitor at the extraction line(EXT-ICT). The bunch spacing is 308ns(302.4ns). In spite of the very low intensity, we could confirm the basic function of the multi-bunch beam extraction. The observed number of the bunch at the extraction line was 27 due to the stored beam condition of the DR. The last bunch of each train was not stored to the DR at the time.

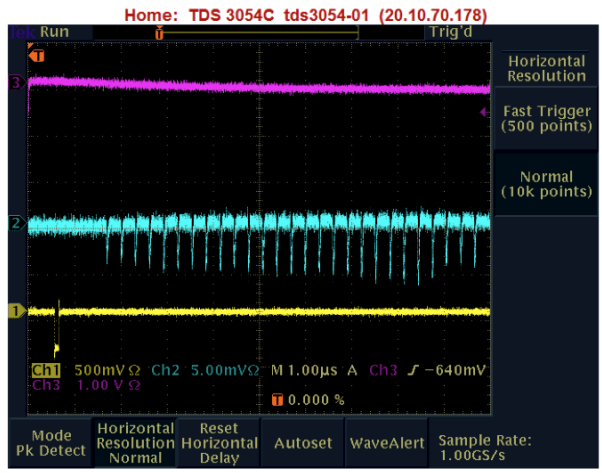

Figure 5: Bunch current at the extraction line

EVALUATION OF KICK ANGLE JITTER OF THE FAST KICKER

The kick angle jitter was estimated from the orbit measurement of the extraction line. The fit from the measured position and the R12 of each location shows the angle distribution of the kicker. Figure 6 shows the result of two sets of the data. Each plot used 700 shots and 400 shots, respectively.

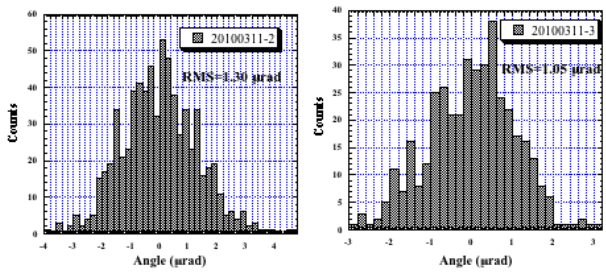

Figure 6: Two sets of the jitter analysis results

The measured angle jitters of the extracted beam were 1.3µrad and 1.05µrad, respectively. The angle jitter ratios for the kick angle were 4.3×10^{-4} and 3.5×10^{-4}, respectively. These results showed that the strip-line kicker has a good stability comparable to the double kicker system of the pulse magnet.

We observed that most of the jitters were coming from the timing jitter of the pulse, which strongly depends on the characteristics of the pulser.

TRIGGER SYNCHRONIZATION WITH THE BEAM TIMING AT THE DISPERSION MEASUREMENT

The kicker trigger signal is made by using programmable delay counters. The origin of the trigger is the injection timing, which is counted about 400ms, using 357MHz (2.8ns period) reference clock. The accuracy of the counter was about 5ps, which did not take into account the cable expansion of the transfer line. The

frequency scan is needed for the dispersion measurement. The problem is the count error at the frequency scan when the clock signal moves across the input trigger timing, some of the counter counts one and the others counts zero. Because the phase of the clock signal is different for each counter, there is a probability that the count error happens at the frequency scan for the kicker trigger. If the count error happens, then the trigger shifts 2.8ns and the fast kicker cannot extract the beam.

We introduced a re-synchronization circuit, which detects the beam timing from the DR BPM, then re-makes the trigger signal from the kicker trigger and BPM signal.

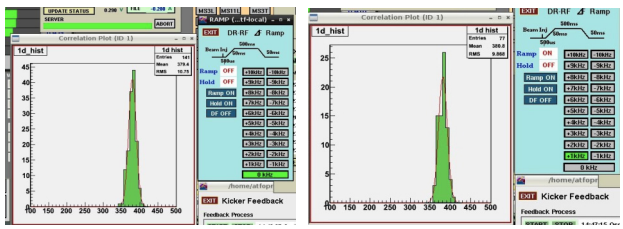

Figure 7: Beam position distribution in the cases of frequency ramp-off (left) and frequency ramp-on 1kHz(right). The horizontal axis is horizontal position(μm) and the vertical axis is the number of pulses.

The beam position distribution for the horizontal direction was measured in the case of the frequency ramp on and off condition to confirm the difference of the kick angle jitter(Figure 7). The measurement used the MQM16FF cavity BPM. Similar position distribution was observed, which is evidence that the re-synchronization circuit works properly. We also confirmed the dispersion correction of the ATF2 beam line by the beam profile change of the MS1IP wire scanner (Figure 8). The measured size was limited to 1.4μm due to the wire size.

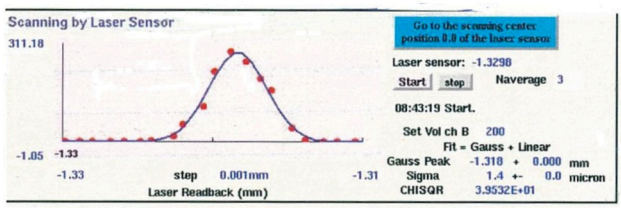

Figure 8: Sample of the vertical beam size measurement

NEXT STEPS

In the case of the single bunch beam extraction, the fast kicker confirmed that the stability of the ATF2 beam tuning was sufficient. However, for the multi-bunch beam extraction, we need additional studies. The kick angle and the angle jitter were different for each pulse of the pulser. Figure 9 shows the time delay from the input to the output for the number of pulses of the FID pulser. The delay was different for each pulse, which means all pulses can not be adjusted to the optimum timing. The characteristics of the time delay were different for each pulser.

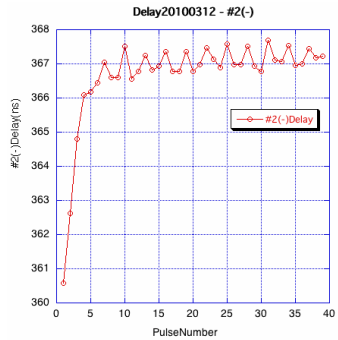

Figure 9: The time delay from input to output as a function of the number of the pulse

To measure the beam quality of the extracted beam of the multi-bunch, we need to develop the following items: multi-bunch monitor system at the extraction line, stable laser system to generate 5.6ns multi-bunch spacing, stable multi-bunch storage in the DR, etc.

SUMMARY

The beam extraction experiment using the proto-type strip-line kicker has been carried out at KEK-ATF. The stored multi-bunch beam in the DR was extracted successfully with different bunch spacing. The pulse bump and the auxiliary septum worked stably. The re-synchronization circuit was used for the precise timing adjustment. The angle jitter of the single bunch beam was 3.5×10^{-4}, which was better than the pulse magnet and thyratron system. The stability of the extracted beam was confirmed with the beam profile measurement of the wire scanner.

ACKNOWLEGEMENT

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