Progress with kicker studies
at KEK-ATF

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**Parameters of ILC**

The length of the bunch train in the linac is ~300km long which should be compressed in the DR and should be decompressed at the downstream of the DR.

**parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch train</td>
<td>5640(2820) bunches</td>
</tr>
<tr>
<td>Bunch charge</td>
<td>2nC/bunch</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>154(308)ns</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>5Hz</td>
</tr>
</tbody>
</table>

![Diagram of electron and positron production and detection](image-url)
**Beam cycle of DR**

**Bunch spacing**

154(308)ns

C = 6km
Freq. = 50kHz (20micro-sec)

Injector

DR

3.08(6.15)ns

To main linac

Kicker pulses for Beam extraction

1st pulse

2nd pulse

3rd pulse

Kicker pulses for Beam injection

~60 trains

Beam Storage Sequence in DR

Injection

5640(2820) bunches

200ms

1ms

Stored Beam

Extraction

Injection

200ms

1ms

Stored Beam

Extraction

Injection

Train N+2

Train N+1

Train N

308ns

2

1
**ILC DR kicker parameters**

Injection/extraction kicker makes the orbit change form the injection orbit to the DR orbit/ from the DR orbit to the extraction orbit.

**Specification**

- Kick angle: $\theta \sim 0.6\text{mrad}$ or $\int Bdl \sim 0.01Tm@5\text{GeV}$, $\beta \sim 50\text{m}$
- Stability: $7 \times 10^{-4}$
- Rep. Rate: $6.5(3.25)\text{MHz}$, 1ms burst, 5Hz
- Rise/fall time: $< 3.08 (6.15) \text{ns}$

07.3.5
Ordinary kicker system (pulse magnet)

The pulse magnetic field is produced by the LC type pulse magnet. The charged high voltage is switched by the tyratron and the high current go through the pulse magnet.

There is a Cutoff frequency ($\omega_c$) for the pulse magnet and the raise time limitation for the tyratron. 

\[
\tau = \frac{\beta}{\omega} = \frac{2}{\omega_c} = \sqrt{2LC}
\]

\[
Z_o = \frac{L}{\sqrt{2C}}, \quad \omega_c = \sqrt{\frac{2}{LC}}
\]
New proposal for the ILC kicker

Fourier series kicker

Beam-Beam kicker

RF deflector

Strip-line kicker

07.3.5
**Kick field of the strip-line kicker**

![Diagram of strip-line kicker and pulse waveform]

\[ \Delta \theta \propto \int_{t}^{t+2L/c} V(t)dt \]

- **Rectangular pulse**
  - Input Pulse
  - Effective Field for the beam \( T = 2L/C \)

- **Trapezoid pulse**
  - Input Pulse
  - Effective Field for the beam \( T = T_r + 2L/C \)

- **Kick field (calc.)**
  - Rise time: 1%~100%
  - Fall time: 100%~1%

- **Pulse waveform**
  - Rectangular pulse
  - Trapezoid pulse

- **The counter direction kicker pulse makes the transverse kick to the beam (Panofky-Wenzel theorem)**
- **The kick field is defined as the integration of the electromagnetic field when the beam go through the strip-line.**

07.3.5
Design of Strip-line kicker system

\[ \Delta \theta = 2g \frac{eV L}{E d} \]

- \( L \): strip – line length
- \( d \): distance between the electrodes
- \( V \): pulse voltage
- \( E \): Beam energy

\[ g = \tanh \left( \frac{\pi \omega}{2d} \right) \]

- \( \omega \): strip – line width
- \( d \): distance between the electrodes

~20 units for 0.6mrad kick angle
Design of Strip-line electrode

The shape of the electrode is designed to keep good uniformity of the deflecting field. The calculated flatness is 0.07% in the area of +/-1.8mm from the center.

Max field 200.7kV/m

127.6kV/m

Geometric factor (analytical) = 0.955
Pulse power supply

There is 3 types of candidates for the kicker pulse source.

1) HTS-50-08-UF (BEHLKE GmbH)
   FET ON switch module
2) Adder Drive Boards (LLNL)
   FET ON switch (stacked)
3) FPG 5-3000M (FID GmbH)
   Fast Recovery Diode OFF switch
BEHLKE HTS-50-08-UF

Connection

1) Star-type grounding
2) For high frequency bursts only
3) Impedance matching (0-50 Ohm)
4) Dynamic compensation (0-100 pF)

Rise time ~3ns at 2.5kV output

Burst pulses (1MHz, 500 pulses)
droop: $5 \times 10^{-3}$
This high voltage pulse power supply is basically developed for the drive pulse of the induction linac.
+/-3.1kV, 500kHz, 500 pulses, ~4ns rise time, 10ns pulse width
FET(DE275) on time: 2ns
**FID FPG5-3000M(1)**

- **External triggering**
- **FID**: Fast Ionization Dynistor
- **DRD**: Drift step Recovery Diode

![Circuit Diagram](image)

- **Amplitude (V)**
  - 0
  - 1000
  - 2000
  - 3000
  - 4000
  - 5000
- **Time (us)**
  - -200
  - 0
  - 200
  - 400
  - 600
  - 800
  - 1000

**Single pulse waveform**

- **$U_{DRD}$**: 1.5 ns
- **$I_{DRD}$**: 100 ns
- **Peak current 300 A**

**Burst pulses (3MHz, 3000 pulses)**

- **Droop**: $\sim 3\%$
FID FPG5-3000M(2)

Pulse width (FWHM) = 2ns
Pulse height = 5.8kV
Rise time = ~1.5ns (5%~95%)
Time jitter = ~29ps
Amplitude Jitter = 0.72%
( limited by the scope resolution)
# Comparison of pulse power supplies

<table>
<thead>
<tr>
<th></th>
<th>Rise Time</th>
<th>High Voltage</th>
<th>Rep. rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTS-50-08</td>
<td>3ns (\uparrow)</td>
<td>2.5kV (\uparrow)</td>
<td>1MHz (\uparrow)</td>
</tr>
<tr>
<td>Adder Drv.</td>
<td>4ns (\uparrow)</td>
<td>&gt;+/-3.1kV (\bigodot)</td>
<td>&gt;500kHz (\uparrow)</td>
</tr>
<tr>
<td>FPG5-3000M</td>
<td>1.5ns (\bigodot)</td>
<td>5kV (\bigodot)</td>
<td>3MHz (\bigodot)</td>
</tr>
</tbody>
</table>
**Beam kick experiment at ATF-DR**

**A)** Kick angle measurement by Single-shot BPM

**B)** Rise/fall time measurement by Turn-By-Turn BPM

**C)** Rise/fall time improvement by Waveform compensator
Strip-line electrode for ATF-DR experiment

Two strip-line electrodes are used for the experiment which was designed for tune measurement of ATF-DR.

Strip-lines

Pulse power supplies
Single-shot BPM system

Resolution: $\sim 2\mu m (\text{rms})$ at $1 \times 10^{10} \text{e}$

(Electronics)
Result of kick angle measurement

The kick angle is estimated from the kicked orbit and R12. The graph shows one turn orbit just apply the beam kick. The kicked orbit starts from #70 BPM. The bellow graph shows the kick angle calculation by SAD.

\[
\text{min.} \sum [\theta \cdot R12 - \Delta x]
\]

Kick angle = 91.1 +/- 1.8\(\mu\)rad
BPM Error(1\(\sigma\)) mean = 6.6\(\mu\)m

Kicked orbit fit by SAD
Turn-By-Turn(TBT) BPM system

Beam oscillation during 4000 turn

Frequency spectrum
\[ y' \propto F(f) \]
This measurement can avoid the noise effect from the other frequencies.
Timing scan of the kick pulse

Beam kick profile
The timing of the kick pulse is scanned for the beam timing with 200ps steps.

Kick angle is estimated from the amplitude of the betatron frequency of the FFT signal.

Rise time = 3.2ns
(1%~100%)
Fall time = 4.0ns
(100%~1%)
**Measurement error**

\[ \sigma_{\text{error}} \approx 3\% \]

Linearity of the oscillation amplitude

The Betatron amplitude of FFT is affected by the impedance effect, chromaticity, dynamic aperture, etc. The measurement need to choose minimize these effects.
Waveform compensator

Simulation of waveform compensator

**Experimental set up**
The rise/fall time can be improved by the combination of the positive and negative pulses which have different timings and different amplitudes.
Waveform simulation

The rise time simulation for the timing and the amplitude of the compensation pulse
Rise time improvement with Waveform compensator

Rise time = 2.2 ns

Zero cross

Rise/fall time improvement v.s. timing
Timing jitter

The zero cross point of two pulses didn’t reach to zero in the measurement. The reason comes from,
- the timing jitter between the beam and the kick pulse.
- the amplitude depends on the slope of the kick field.
- it is agreed with the simulation in the case of the 80ps time jitter.
To cure the effect, the timing jitter has to be minimize.
ATF2 - 40nm beam production, measurement, single bunch and multi bunch beam handling
Present beam extraction (Pulse magnet kicker system)

Kick angle Stability
$1 \times 10^{-3} \rightarrow 2.8 \times 10^{-4}$

308ns pulse width

3 bunches, 154ns spacing
Beam extraction experiment with strip-line kicker

Multi-bunch beam extraction with strip-line kicker is under designing. One of the problem is no space for the strip-line kicker electrodes. We are considering to add the pulse bump orbit.

07.3.5
Summary

1. Development work of Multiple unit strip-line kicker system is carrying out at KEK-ATF. The tentative strip-line electrode shape is designed.

2. Three type of the pulse power supply are evaluated for the strip-line kicker pulse source.

3. The beam kick test of the single unit was carried out in the KEK-ATF DR. The measured rise time is 3.2\text{ns} and the fall time is 4.0\text{ns}, respectively.

4. The rise/fall time improvement by the waveform compensator was tested. The rise time is improved up to 2.2\text{ns}.

5. The beam extraction from the DR to the extraction line is under designing for the multi-bunch extraction which is same scheme of the beam extraction from ILC-DR to RTML.