Performance of the TTF Photoinjector Laser System

S. Schreiber, DESY
Laser Issues for Electron Photoinjectors, October 23-25, 2002, Stanford, California, USA
& I. Will, A. Liero, W. Sandner, MBI Berlin

😊 Overview of the TESLA Test Facility Photoinjector

😊 Performance its laser system

😊 Summary
# The TTF Injector

**Design Parameters**

<table>
<thead>
<tr>
<th></th>
<th>TTFL(a)</th>
<th>TTFL(b)</th>
<th>TTF-FEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF frequency of acc. structures</td>
<td>1.3 GHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repetition rate</td>
<td>10 Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse train length</td>
<td>800 us</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse train current</td>
<td>8 mA</td>
<td>9 mA</td>
<td>9 mA</td>
</tr>
<tr>
<td>Bunch frequency</td>
<td>1 MHz</td>
<td>2.25 MHz*</td>
<td>9 MHz *(optional 54 MHz, 2 mA)</td>
</tr>
<tr>
<td>Bunch charge</td>
<td>8 nC</td>
<td>4 nC</td>
<td>1 nC</td>
</tr>
<tr>
<td>Bunch length (rms)</td>
<td>1 mm</td>
<td>1 mm</td>
<td>0.8 mm</td>
</tr>
<tr>
<td>Emittance norm, x,y</td>
<td>20 um</td>
<td>10 um</td>
<td>2 um</td>
</tr>
<tr>
<td>Energy spread (rms)</td>
<td>0.1 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injection energy</td>
<td></td>
<td></td>
<td>20 MeV</td>
</tr>
</tbody>
</table>

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**RF-Gun**
- 1300 MHz
- 1 1/2 Cells
- 40 MV/m

**Capture Cavity**
- TESLA 9-cell structure
- 15 MV/m

**Kryomodule**
- Laser
  - UV (262 nm)
  - mode-locked pulse train oscillator
  - synchronized to RF
- Cs2Te, QE = 0.5 %

**Beam Diagnostics**
- Energy spread
- Bunch length
- Emittance
- Transvers profile
- Charge

**Matching Section**
- Match beam to linac lattice
- HOM experiments

**Bunch Compressor**

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S. Schreiber
24-Jun-2000
TTF RF Gun

1 1/2 cell rf gun
1.3 GHz
RF pulse length 900 µs
rep rate 1 Hz
laser driven with Cs2Te cathode

Side view of the RF gun
Based on Nd:YLF laser material
-> long fluoresc. lifetime, low thermal lensing

Locked to the TTF RF:
-> phase stability < 1 ps (< 0.5 dg of 1.3 GHz rf)

Generates a 800 µs long pulse train in the UV
-> 1 to 10 Hz rep rate,
-> 1 MHz or 2.25 MHz (54 MHz option) within train

UV single pulse energy
-> 25 uJ (1 µJ required for 1 nC)

Energy stability
-> < 5 % peak-peak within pulse train
< 10 % peak-peak from shot-to-shot

Uses relay imaging to create a
and to enhance
-> transverse flat-top profile
-> the pointing stability < 2 urad

Pulse length in UV
-> sigma = (7.1 ± 0.6) ps
The laser system has been built by the Max-Born-Institut Berlin (MBI) together with DESY and was installed in 1997.

Credits:
- The laser technology has been mainly developed by MBI (I. Will et al).
- Laser facility, laser beam line, TTF control system integration, interlocks etc. by DESY (credits to K. Rehlich, A. Agababyan, M. Staack, E. Sembrowski).

From the installation of the FNAL RF gun in fall 1998, the laser has been operated almost continuously 24 h/day, 7 days/week.

Running time up to now:
- 23000 h with 8.4 $10^7$ shots (PTO)
- with 5.7 $10^7$ shots (amplifiers)

Main failure mode:
- External cooling water supply
- Main maintenance
- Flashlamp exchange (5 $10^6$ shots)
Scope Trace of the Laser Pulse Train

- **Phase of Laser Pulses with respect to Reference RF (1.3 GHz)**
- **Photodiode Signal of Laser Pulse Train after Amplification (1 or 2.25 MHz)**
- **Photodiode Signal of Laser Pulse Train in the Oszillator (54 MHz)**

1 ps
18.5 ns
800 us
1 or 0.4 us
Laser Pulse Energy and Charge along the Train of 800 us length

Laser pulse train measured with a photodiode

Laser UV reflected from the cathode

Charge measured with a toroid

S. Schreiber
28-Jun-2002
Laser Pulse length in UV measured with a streak camera

✿ laser pulse length $\sigma = 7 \pm 1$ ps

in this example: $\sigma = 8.5$ ps
Charge Stability

Charge measured at ICT B1 rf gun exit
Laser energy from photodiode (green)

In this case:
charge av = 2.3 nC, 5.7 % rms
(smallest 3 %, seen also > 10%)
Example of charge fluctuation in a flat pulse train

In this example:

- pulse train length 100 us (1 MHz)
- average charge over the train 2.2 nC
- rms fluctuation along the train 0.014 nC = 0.6 %
Example of charge fluctuation in a less flat pulse train

In this example, the train is less flat:

- pulse train length 150 us (1 MHz)
- average charge over the train 2.1 nC
- rms fluctuation along the train 0.06 nC = 2.8 %
Long Term Charge Fluctuations within a Pulse Train

Data from the long pulse train run on 17-Feb-2002
Collected over 8 hours, 8229 trains of > 50 us,
for each train, the average bunch charge is calculated

![Histogram of average bunch charge](image1)

- **nb = 8229**
- **mean = 2.15**
- **rms = 0.044**
- **rms = 2.0%**

The charge variation along the train is
for short trains 1% rms, for longer trains 3% rms

![Histogram of RMS charge fluctuation](image2)
Example for the Modulation of the Beam

Here: modulation frequency 250 kHz
modulation depth of beam 80 %

Modulation frequency selectable from 100 kHz to 27 MHz

Modulation depth adjustable from 0 to 100 %
Sinusoidal content about 90 %

S. Schreiber, 08-May-2001
Example 54 MHz pulse train for the HOM experiment

脉冲列测量的是BPM的求和信号

脉冲列持续400μs

S. Schreiber 21-Oct-2002
Operators panel to control the laser

TTF Laser

LaserStatus FSM
No WARNING

Error in Laser status: -
Error in time settings: -
What to do: -

Laser Amplifiers
Rate: \( \frac{1}{1} \) Hz
Run
Stop

Pulse Train Stop (s)
Train length = Stop - 0.0022003 s

Check 1.3 GHz Phase:
Show Good Reference
if bad:
Optimize Resonator length
Restore Settings

Status
Mains on
Power Supplies on
PTO on
Slow Feedback on
Shutter open
Misc.

Temp Laser
Show Interlock

Example
Example
PTO output
Ph. Diode
UV at Gun
Start Laser
Xpert
**TTF Control System**

Operators panel to tune the pulse train oscillator (PTO) length

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### TTF Laser Slow Feedback

<table>
<thead>
<tr>
<th>If you prefer automatic tuning --&gt;</th>
<th>Auto</th>
<th>Show Scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>If you prefer manual tuning:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Switch off laser amplifiers --&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Switch off slow feedback -</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Setpoint</th>
<th>Switch On</th>
<th>Off</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.997</td>
<td></td>
<td></td>
<td>1.027</td>
</tr>
</tbody>
</table>

3. resonator length tuning with stepper motor

- Temperature: 22.8°C, 25.6°C
- Length: 5793
- Steps due: 0

![Graph](image-url)

**Graph Details:**
- Res = 1, Buf = 0
- Axes: [1000 - 3500] s, [0 - 40] V

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If you prefer manual tuning:

1. Switch off laser amplifiers -->
2. Switch off slow feedback -

---

**Steps due:**
- +1, +10
- -1, -10

**Length:** 5793

**Steps due:** 0

---

**Graph:**
- Axes: [1000 - 3500] s, [0 - 40] V
- Res = 1, Buf = 0
<table>
<thead>
<tr>
<th></th>
<th>Specification</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>pulse train</td>
<td>800 pulses spaced by 1 µs</td>
<td>achieved</td>
</tr>
<tr>
<td>repetition rate</td>
<td>10 Hz</td>
<td>achieved (TTF runs at 1 Hz)</td>
</tr>
<tr>
<td>pulse energy</td>
<td>5 µJ</td>
<td>up to 50 µJ</td>
</tr>
<tr>
<td>pulse length (in UV)</td>
<td>2 to 10 ps flat-top</td>
<td>adjustable</td>
</tr>
<tr>
<td>transverse profile</td>
<td></td>
<td>7.1 ± 0.6 ps</td>
</tr>
<tr>
<td>flat-top</td>
<td></td>
<td>achieved</td>
</tr>
<tr>
<td>homogeneity</td>
<td>± 10 %</td>
<td>partially achieved</td>
</tr>
<tr>
<td>energy stability</td>
<td>(peak-peak)</td>
<td>± 5 %</td>
</tr>
<tr>
<td>- train to train</td>
<td>± 10 %</td>
<td>± 10 %</td>
</tr>
<tr>
<td>- pulse to pulse</td>
<td>± 10 %</td>
<td>&lt; 2 µrad</td>
</tr>
<tr>
<td>pointing stability</td>
<td>-</td>
<td>achieved</td>
</tr>
<tr>
<td>synchronization</td>
<td>to reference rf signals</td>
<td>&lt; 1 ps (rms)</td>
</tr>
<tr>
<td>phase stability</td>
<td>1 ps (rms)</td>
<td></td>
</tr>
<tr>
<td>availability during runs</td>
<td>high</td>
<td>98 %</td>
</tr>
</tbody>
</table>

😊 running time 23000 h with 8.4 \(10^7\) shots (PTO)
with 5.7 \(10^7\) (amplifiers)