Performance of the TTF Photoinjector for FEL Operation

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😊 Overview of the TESLA Test Facility Injector and Linac for FEL operation

😊 Performance of the injector and properties of the beam delivered to the undulator
  -> transverse emittance
  -> bunch length
  -> energy spread

😊 Conclusions
## The TTF Photoinjector

### Design Parameters

<table>
<thead>
<tr>
<th>Parameter</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</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>20 MeV</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Cathode System
- Cs$_2$Te, QE > 0.5%

### RF-Gun
- 1300 MHz
- 1 1/2 Cells
- up to 50 MV/m

### Booster
- TESLA 9-cell superconducting cavity 15 MV/m

### Laser
- UV (262 nm) mode-locked pulse train oscillator
- synchronized to rf

### Beam Diagnostics
- Energy spread
- Bunch length
- Emittance
- Charge

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

### Bunch Compressor
- Compress down to 1 mm

### Kryomodule
- Laser
- UV (262 nm) mode-locked pulse train oscillator
- synchronized to rf

S. Schreiber
15 Jun 2001
In operation since Dez. 1998
--> about 14 000 h and 5 E7 shots

### TTF RF Gun Operating Parameters

**Frequency** 1.3 GHz  
**Number of cells** 1 1/2  
**Half Cell length** 5/4 λ/4  
**RF Coupling** transverse  
**Gradient on Cathode** 35...42 MV/m  
**Repetition Rate** 1 ... 5 Hz  
**RF Pulse Length** 900 µs  
**Klystron Power** 2.7 MW @ 39 MV/m  
**Av. Dissipated Power** 12 kW @ 5 Hz  
**Cathode** Cs2Te or CsKTe

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FNAL/INFN LASA/MBI/DESY

S. Schreiber  
15-Jun-2002
**The Laser System for the TTF Photoinjector**

- **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
  (up to 10 Hz rep rate, 1 MHz or 2.25 MHz within train)
- **UV single pulse energy 25 µJ**
  (1 µJ required for 1 nC)
- Energy stability < 5 % peak-peak within pulse train
  and < 10 % peak-peak from shot-to-shot
- Uses relay imaging to create a transverse flat-top profile
  and to enhance the pointing stability < 2 urad
- **Pulse length in UV sigma = (7.1 ± 0.6) ps**

S. Schreiber
16-Oct-2000
Scope Trace of the Laser Pulse Train

- 800 us
- 1 ps

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)

18.5 ns

1 or 0.4 us
Cs$_2$Te cathode: high quantum efficiency > 0.5%

A load lock system allows to change cathodes without breaking the UHV vacuum
Vacuum better than $10^{-10}$mbar required to maintain high quantum efficiency

The cathodes are prepared off site in Milano and transported under UHV condition to DESY
Overview of the TESLA Test Facility Linac

Experiments with FEL Radiation

4 MeV 16.5 MeV 120 MeV 250 MeV

RF-Gun Booster Superconducting TESLA Accelerating Modules Undulator

Bunch Compressor Bunch Compressor

Laser Beam Dump
Remark concerning the design

The TTF injector has been designed for TESLA applications:
-> design fulfills requirements for a TESLA type beam to test the superconducting accelerating structures

To drive the TTF-FEL phase 1, demands are tighter:
the FEL needs

1. high peak current > 0.5 kA
2. small energy spread < 0.1 %
3. small transverse emittance < 6 um

The rf gun source can do 2. and 3., but not 1.
-> the peak current is limited by space charge effects
That’s why bunch compression after acceleration is required

Do have the compression working correctly, the rf induced energy spread must be small
-> short bunches of 0.8 mm length required before acceleration

But this is shorter than the rf gun can do keeping at the same time the transverse emittance small
RMS Bunch Length after Booster

measured as a function of rf gun phase with a streak camera (Photonetics)
Charge: 1 nC, nominal rf gun settings

Simulations for laser pulse length $\sigma_L = 10 \ldots 14$ ps (indicated by the number)

S. Schreiber
28-Jun-2002
Energy Spread Measurement

TTFL Injector Spectrometer

beam profile measured using optical transition radiation

from a gaussian fit to the core:

$\sigma_E = 22.1 \pm 2.7 \text{ keV}$

$\sigma_E / E = 0.13 \pm 0.02 \%$

tail: up to 50 keV

S. Schreiber
15-Jun-2001
We expect a sharp peak and a long tail.

The peak sharpness reflects the uncorrelated energy spread from the injector of ~20 keV.
Bunchlength measurement with a streak camera

Syncrotron light from the last dipole has been measured with a fast streak camera (FESCA 200 Hamamatsu).

For comparison:
Profile obtained with tomographic method (M. Hüning)

Estimated peak current: 0.6 kA
30% of the charge of 3 nC is in the peak

S. Schreiber
29-Jun-2002
Quadscan for Different Solenoid Fields

Charge 1 nC, Energy 17.2 MeV, exit booster

<table>
<thead>
<tr>
<th>Sol. 1/2</th>
<th>emit. x</th>
<th>emit. y (mm mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200/104 A</td>
<td>4.19 ± 0.13</td>
<td>4.58 ± 0.15</td>
</tr>
<tr>
<td>220/104 A</td>
<td>3.02 ± 0.17</td>
<td>3.47 ± 0.12</td>
</tr>
<tr>
<td>beta (m) = 0.39 ± 0.03 / 0.51 ± 0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>alpha = 0.78 ± 0.06 / 0.6 ± 0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>240/104 A</td>
<td>4.08 ± 0.57</td>
<td>4.52 ± 0.47</td>
</tr>
</tbody>
</table>

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15-Jun-2001
Development of the emittance along the linac

rf gun parameters:
1 nC, 40 MV/m, spot size r=1.5 mm, phase 40 deg, Solenoids 0.105/0.088 T, booster 12 MV/m

After the booster:
3.0 (3.2) +- 0.5 mm mrad hor. (vert)

After acceleration to 137 MeV:
8 (9) +- 2 mm mrad hor. (vert)

After acceleration to 246 MeV:
11 +- 6 (7 +- 2) mm mrad hor. (vert)
The projected emittance grows with compression and higher charges.
Problem: we measure only the projected emittance

Estimated slice emittance from FEL radiation properties and the gain length ($67\pm5$ cm)

TTF-FEL
Conclusion

😊 The TTF photoinjector is in operation since Dec. 1998 (14 000 h with beam or 5 E7 shots)

😊 It has been originally designed for TESLA beam parameters and is used to drive the TTF-FEL as well.

😊 The effect of rf curvature when accelerating long bunches produces
   --> a sharp peak in the longitudinal profile after compression

😊 This peak fulfills the requirement for the
   --> peak current 0.6 kA (from streak camera data)
   --> slice emittance 4.5 mm mrad (from FEL properties)

😊 In this way, saturation of the TTF SASE-FEL at 95 - 105 nm has been achieved (10-Sep-2001).

😊 --> To drive a SASE FEL, an electron source design has to include the whole linac in order to evaluate the performance of the beam entering the undulator