The TESLA XFEL Project

Hans Weise / DESY for the XFEL Group
integrated into TESLA LC proposal: using part of e⁻ linac, two extraction points, long beam transfer → cost effective but less flexible solution
TDR update 2002:

- **XFEL driver linac separate from LC**
- **de-coupling of the XFEL from the Linear Collider regarding construction & operation**
  (and: **approval**)
- maintaining common site
- identical linac technology
- detailed analysis of potential gain in flexibility was not included in the update

Since then...

- SASE FELs in operation
- LCLS project
- XFEL is a **European project**
- new site close to DESY
- TESLA linac technology
- detailed analysis of **flexibility** with respect to photon beam time structure
- **detailed planning** started
Basic Accelerator Layout

The XFEL starts on the DESY site. The tunnel is approx. 15 to 30 m deep underground. The linac is below an urban area. An almost rural area offers sufficient space for the experiments hall.
**XFEL Linac Layout**

- **100 MeV**
  - Injector I
  - 3rd Harmonic
  - Booster

- **500 MeV**
  - Bunch Compressor
  - Main Linac >100 Modules

**XSIN**
- ca. 270 m

**Booster**
- ca. 150 m

**Main Linac**
- ca. 270 m

**Compressor**
- ca. 150 m

**XS1**
- ca. 450 m

**XTL**
- 100 MeV
  - Injector II
  - XSE

**3rd Harmonic**
- 50 m

**Injector II**
- 80 m

**Collimator**
- Switchyard

**Undulators**
- ca. 1150 m

**Dumps**
- Photon Beamlines
## Reference Parameters

<table>
<thead>
<tr>
<th>Main linac</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy gain</td>
<td>0.5 $\rightarrow$ 20 GeV</td>
</tr>
<tr>
<td># installed modules</td>
<td>116</td>
</tr>
<tr>
<td># active modules</td>
<td>104</td>
</tr>
<tr>
<td>acc gradient</td>
<td>22.9 MV/m</td>
</tr>
<tr>
<td># installed klystrons</td>
<td>29</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>200 ns</td>
</tr>
<tr>
<td>beam current</td>
<td>5 mA</td>
</tr>
<tr>
<td>$p_{\text{beam}} \rightarrow$ beam p. klystron</td>
<td>3.8 MW</td>
</tr>
<tr>
<td>incl. 10% + 15% overhead</td>
<td>4.8 MW</td>
</tr>
<tr>
<td>matched $Q_{\text{ext}}$</td>
<td>$4.6 \cdot 10^6$</td>
</tr>
<tr>
<td>RF pulse</td>
<td>1.37 ms</td>
</tr>
<tr>
<td>Beam pulse</td>
<td>0.65 ms</td>
</tr>
<tr>
<td>Rep. rate</td>
<td>10 Hz</td>
</tr>
<tr>
<td>Av. Beam power $^*$</td>
<td>650 kW</td>
</tr>
<tr>
<td>Total AC power</td>
<td>$\approx$ 9 MW</td>
</tr>
</tbody>
</table>

* Power limitation to $\sim$300kW per beamline $\rightarrow$ solid beam dump possible
TESLA Test Facility as Prototype for the XFEL

RF gun
Laser
4 MeV

bunch compressor
150 MeV

accelerator modules

bunch compressor
450 MeV

collimator
undulators
bunch compressor
1000 MeV

bypass

FEL experimental area

H. Weise / DESY

EPAC 2004 / Lucerne
The goal for the XFEL:
- charge: 1nC
- $\varepsilon_{x,y}$: 1.4 µm
- $\sigma_z$: ~20 µm (80 fs)
- $\sigma_E$, uncorr: < 2.5 MeV

At TTF and PITZ (DESY) we are already close to these parameters.
Injector R&D in the TESLA Collaboration

- Cathode development at INFN Milano.
- Simulation code development at DESY and FNAL.
- 3\textsuperscript{rd} harmonic cavities at FNAL.
- Experimental investigations at the A0 Photo injector at FNAL.
- Injector operation at TTF I and TTF II.
- Experimental investigations at the Photo Injector Test stand in Zeuthen PITZ.

Cs\textsubscript{2}Te cathode used at PITZ May-Sept '03

$200 \text{ mm}$

$100 \text{ mm}$

Cs\textsubscript{2}Te cathode used at PITZ May-Sept '03

$200 \text{ mm}$

Cs\textsubscript{2}Te cathode used at PITZ May-Sept '03

$200 \text{ mm}$
From TTF II to the XFEL Injector

TTF II parameters have been achieved at PITZ (DESY Zeuthen).
In order to reach the XFEL parameters we have to:

• increase the gradient on the cathode from 40 MV/m to 60 MV/m this is scheduled for the next running period at PITZ
• further improve the transverse and longitudinal laser profile an on-going program in collaboration with the Max-Born Institute
Electro-Polishing becomes State-of-the-Art Surface Preparation Technique

Electro-polished Cavities Measured in Vertical Test

Unloaded Quality Factor

Accelerating Gradient (MV/m)

- AC70
- AC72
- AC73
- AC78

Electro-Polishing becomes State-of-the-Art Surface Preparation Technique.

H. Weise / DESY

EPAC 2004 / Lucerne
The inter-cavity connection is done in class 10 clean rooms

The assembly of an 8 cavity string
• is a standard procedure
• is done by technicians from the TESLA Collaboration
• is well documented using the cavity database as well as an Engineering Data Management System
• was the basis for two industrial studies.

We are ready to transfer this well known and complete procedure to industry.
TTF Linac Accelerator Modules

New Generation as XFEL Prototype

- Reduced diameter
- New concepts accommodate for longitudinal shrinkage during cool down
RF Unit of the XFEL (32 cavities)

- De-rated 10MW MBK
- Bouncer-type modulator
- 5 MW RF source
- Variable Q_ext with adjustable coupler and/or waveguide tuner
- 12m TTF-like acc. modules
- Eight 9-cell Nb cavities at 2K, $Q_0 = 10^{10}$
XFEL RF Unit

1 klystron for 4 accelerating modules, 8 nine-cell cavities each

MBK Klystron

Low Level RF System

vector modulator

DAC
DAC

vector sum

MFK Klystron

vector modulator

Mechanical tuner (frequency adj.)

circulator

stub tuner (phase & Qext)
coaxial coupler

cavity #1
cavity #8

vector demodulator

accelerator module 1 of 4
Accelerator is housed in a 5.2 m diameter tunnel ~ 15 - 30 m underground.

Klystrons in tunnel are connected to modulators in an external hall by 10kV pulse cables.

Preferred installation concept is suspension from tunnel ceiling.
Future users ask for:
- Homogenous filling
- Homogenous filling with variable bunch distance
- Homogenous filling with variable bunch distance and bunch number
- Sub-trains with variable distance and bunch number
- Pilot bunches ahead
- Pump and probe (two bunches spaced by one / a few RF buckets)
- Wavelength variation of a few percent inside a bunch train, i.e. energy variation

Generation of bunch train patterns:
- At the source  
  → varying transient effects in the entire accelerator (handled e.g. by the LLRF system)
- At the beam delivery / distribution system  
  → more challenging kicker devices
**Electron Beam Distribution**

![Diagram showing electron beam distribution](image)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Details</th>
</tr>
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<tbody>
<tr>
<td>DC Magnet</td>
<td>One beamline only&lt;br&gt;Commissioning option</td>
</tr>
<tr>
<td>Slow switch pulse to pulse</td>
<td>Duty cycle reduced by number of beamlines&lt;br&gt;TDR option</td>
</tr>
<tr>
<td>High Q Resonator</td>
<td>Fixed bunch pattern, full duty cycle</td>
</tr>
<tr>
<td>Programmable fast kicker</td>
<td>for individual bunches&lt;br&gt;Flexible</td>
</tr>
</tbody>
</table>

- **SASE 1 – 3**
- **Undulator 1 – 2**
- **shafts 1 – 4**
- **beamdump 1 – 2**
- **experimental hall**
- **XFEL, 2nd phase**
The First Detailed Site Drawings
The plan approval procedure requires a detailed site layout.

At present the preparation of this legal procedure is done on the basis of the knowledge we have.

In order to detail the different sections of the XFEL installation, a number of accelerator experts and future users, nominated by their home institutes and the corresponding national funding agencies, are discussing the final layout in two groups:

• Science and Technology Issues (STI) as well as
• Administrative and Funding Issues (AFI).

Both groups are going to come up with a common proposal and a memorandum of understanding by 2005.
Sketch of a Possible Future CW Operation Mode

• Assume that as a result of longer term developments the possibility of Ångstroem FEL radiation at lower beam energy comes in reach, by:
  – Improved beam quality (lower emittance)
  – Shorter period undulators
  – Advanced FEL concepts, etc.
  – Last, not least: experience gained during 1st stage of the facility

• → high duty cycle (up to CW) operation mode may become an attractive future option and should not be excluded in the design
Repetition Rate for Bunch Trains

max rep rate and beam pulse length vs. E_acc
Q_ext varied with E_acc (I Beam=5mA const.)

- \( f_{rep} \) [Hz]
- cryo-limit
- \( T_{beam} \) [ms]

Decreasing \( T_{beam} \) at higher \( f_{rep} \) helps, but injector is an issue!
If you are curious please check http://xfel.desy.de
want to participate
Conclusions

• The 20 GeV s.c. linac based on the technology developed by the TESLA collaboration and successfully demonstrated at TTF / VUV-FEL is an ideal driver for the Free Electron Laser facility, offering a broad range of operating parameters in its baseline design. Future upgrade options can be included.

• With the R&D work towards industrial production of major components and the preparations for the site and the legal procedure (plan approval procedure) well under way, we should be ready to go into construction phase in ~2 years from now.