THREE TRANSVERSE DEFLECTING SYSTEMS FOR ELECTRON BEAM DIAGNOSTICS IN THE EUROPEAN FREE-ELECTRON LASER XFEL*

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INR RAS and DESY have developed three TDS Systems for XFEL project. They are to be installed:
- in the XFEL injector ($z \approx 53$ m)
- In the BC1 section ($z \approx 206$ m)
- In the BC2 section ($z \approx 427$ m)
for the measurement of
- Bunch length
- Longitudinal phase space
- Slice emittance

130 МэВ

600 МэВ

2.5 ГэВ

17.5 ГэВ
**Disk-Loaded Structures**

<table>
<thead>
<tr>
<th>Description</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disk-Loaded Str. with Two Peripheral Holes (LOLA)</td>
<td><img src="image-1.png" alt="Diagram of disk-loaded structure with two peripheral holes" /></td>
</tr>
<tr>
<td>Disk-Loaded Str. with Oval Aperture Hole (h=1.7mm)</td>
<td><img src="image-2.png" alt="Diagram of disk-loaded structure with oval aperture hole" /></td>
</tr>
<tr>
<td>Disk-Loaded Str. with Oval Aperture Hole (h=7.5mm)</td>
<td><img src="image-3.png" alt="Diagram of disk-loaded structure with oval aperture hole" /></td>
</tr>
<tr>
<td>Disk-Loaded Str. with Two Peripheral Recesses</td>
<td><img src="image-4.png" alt="Diagram of disk-loaded structure with two peripheral recesses" /></td>
</tr>
<tr>
<td>Disk-Loaded Str. with Resonant Slot</td>
<td><img src="image-5.png" alt="Diagram of disk-loaded structure with resonant slot" /></td>
</tr>
</tbody>
</table>

**Frequency Shifts**

- $\Delta f = 40\text{MHz}$
- $\Delta f = 40\text{MHz}$
- $\Delta f = 150\text{MHz}$
- $\Delta f = 40\text{MHz}$
- $\Delta f = 900\text{MHz}$
XFEL Transverse Deflecting Systems

XFEL TDS INJ: Structure tuning
TDS System BC1 and BC2: Structure tuning

(file number = 0091)

E corrected [%]

Steps

(file number = 0091)

Phase Shift [deg]

Iris Number
# TDS: Solid State Modulators – Arkadiev type

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>XFEL TDS INJ</th>
<th>XFEL TDS BC1/BC2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of modules in the modulator</td>
<td></td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Max voltage of the module</td>
<td>kV</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>Max voltage of the modulator</td>
<td>kV</td>
<td>48</td>
<td>44</td>
</tr>
<tr>
<td>Max voltage in the modulator with respect to the ground</td>
<td>kV</td>
<td>24</td>
<td>22</td>
</tr>
<tr>
<td>Max current of the modulator</td>
<td>A</td>
<td>166</td>
<td>1420</td>
</tr>
<tr>
<td>Ratio of pulse transformer</td>
<td></td>
<td>2.3</td>
<td>5.7</td>
</tr>
<tr>
<td>Max voltage of the klystron</td>
<td>kV</td>
<td>110</td>
<td>250</td>
</tr>
<tr>
<td>Max current of the klystron</td>
<td>A</td>
<td>72</td>
<td>250</td>
</tr>
</tbody>
</table>
XFEL Transverse Deflecting Systems

XFEL TDS INJ: Modulator

- RF Generator
- Klystron
- Oil Tank
- HV Filament PS
- Choke
- LV Filtration
- Bias Bar
- LV Filament Power Supply
- 230V AC
- SEU1
- SEU2
- 10 kV Module #1
- 10 kV Module #2
- 10 kV Module #3
- 10 kV Module #4
- 10 kV Module #5
- 10 kV Module #6
- Module Power Supply
- Optical Serial Interface
- Modulator PLC
- Modulator Control Module
XFEL Transverse Deflecting Systems

XFEL TDS INJ: Modulator
BLUE is positive voltage
GREEN is negative voltage
RED is differential voltage

- Output differential voltage 50kV and nominal current 170A at 6 \( \mu \)sec, 10Hz.
- Pulse flat-top length \( \tau_{ft} = 0.1-3.1 \mu \text{sec} \) (specs).
  Tested is 6 \( \mu \)sec (flat-top length 5.5 \( \mu \)sec).
- Pulse flat-top voltage uniformity <1%
- Pulse rise time is \( t_r = 0.2 \mu \text{sec} \).
- Pulse fall time is \( t_f = 0.2 \mu \text{sec} \).
- UPS Klystron solenoid power supply
- Computer
- Ethernet switch is ready.
- RF controller
- Touch Screen monitor & Computer
- System controller
- Power distribution

4-channel 200MHz ADC for RF controller

Horizontal axis is the time in the number of samples (200 MHz sample rate). 2000 samples correspond to 10 μsec.
XFEL Transverse Deflecting Systems

TDS HPRF BC1 is under production
CPI klystron VKS-8262HS is used for the PITZ TDS and for XFEL TDS INJ:
- Frequency: 2.998 GHz
- Peak power: 3 MW
- Voltage: 110 kV
- Current: 72 A
- Pulse length: 12 usec
- Drive power: 80 W

THALES klystron TV2002DoD is used for the XFEL TDS BC1 and for XFEL TDS BC2:
- Frequency: 2.998 GHz
- Peak power: 24 MW
- Voltage: 250 kV
- Current: 250 A
- Pulse length: 6.5 usec
- Drive power: 240 W
High power RF test of the TDS HPRF INJ with RF drive of the klystron. Yellow is the klystron voltage. Pink is RF power in the klystron waveguide.

Normal operation

Fast interlock within the pulse in the high voltage breakdown event: high voltage interrupts, and current is limited.
• 55 m long waveguide system for XFEL TDS INJ connects the klystron at -5 floor and the deflecting structure at -7 floor.
• Short waveguide systems connect the klystron and the deflecting structure in the XFEL TDS BC1 and in the XFEL TDS BC2.
• Each waveguide system includes
  • directional coupler,
  • waveguide window,
  • waveguide load,
  • spark detectors,
  • waveguide adapters for ion pumps,
  • E-bends,
  • H-bends,
  • straight waveguides.
### XFEL TDS: Directional coupler

<table>
<thead>
<tr>
<th>Directional coupler unit No.</th>
<th>Coupling S13, dB</th>
<th>Isolation S14, dB</th>
<th>Directivity D, dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-65.9</td>
<td>-103</td>
<td>37</td>
</tr>
<tr>
<td>2</td>
<td>-65.6</td>
<td>-100</td>
<td>34</td>
</tr>
</tbody>
</table>
99.7% Alumina
The load is the rectangular waveguide with reducing height and with Sendust coating.
XFEL Transverse Deflecting Systems

XFEL TDS: Waveguide line
TDS Waveguide System INJ has been assembled at its operating place.
Measured reflection from the Waveguide System and Deflecting Structure in plane of input waveguide flange is $S_{11}=-42$ dB at operating mode.
XFEL Transverse Deflecting Systems

XFEL TDS Systems INJ design
XFEL Transverse Deflecting Systems
XFEL TDS HPRF INJ design
TDS System BC1 consists of
- TDS (deflecting structure)
- HPRF System
TDS System BC2 consists of
- TDS (two deflecting structures - the same as TDS BC1)
- HPRF System
HPRF INJ has been installed at XFEL and tested with resistive load:

- $U=0…110$ kV
- $I=0…82$ A
- at $\tau=6$ μsec
- $F=10$ Hz
- pulse-to-pulse output voltage instability (peak-to-peak) 0.19%
- RMS voltage fluctuation 0.03%
- flat-top voltage non-uniformity <1%
TDS INJ: assembled in the Injector
XFEL Transverse Deflecting Systems

TDS BC2: assembled in the XFEL tunnel
25 JULY 2016
Electron injector for European XFEL exceeds expectations*

The bright X-ray light of the European XFEL is produced by small bunches of high-energy electrons. Bunch length and slice emittance measurements have been done.

1. TDS System INJ has been tuned and installed at XFEL. It operates for the beam diagnostics.
2. TDS Structures and waveguide systems for XFEL TDS BC1 and XFEL TDS BC2 have been manufactured, tuned and supplied to DESY.
3. TDS Structure BC1 will be assembled on the girder in the XFEL tunnel in accordance with XFEL schedule.
4. The modulator for XFEL TDS BC1 is under production. It will be supplied to DESY, tested at the test stand and installed in the XFEL tunnel then.
5. Two TDS Structures BC2 have been assembled on the girder in the XFEL tunnel.
Sincere appreciation to all XFEL TDS cooperation members from

INR RAS, Nano Invest, DESY and MEPHI

for the fruitful and interesting joint work during TDS development, construction and commissioning.

Thank you for attention