Status of the Novosibirsk High Power Terahertz FEL


Budker INP, Novosibirsk, Russia
FEL based on energy recovery accelerator

1 - injector, 2 - accelerating RF structure, 3 - 180-degree bends, 4 - undulator, 5 - beam dump, 6 - mirrors of optical resonator
First stage: ERL and submillimeter (THz) FEL
Features of RF system

- Low frequency (180 MHz)
- Normal-conducting uncoupled RF cavities
- CW operation
Advantages

- High threshold currents for instabilities
- Operation with long electron bunches (for narrow FEL linewidth)
- Large longitudinal acceptance (good for operation with large energy spread of used beam)
- Moderate tolerances for orbit lengths and longitudinal dispersion
A pair of cavities (accelerating section) on a support frame
Main parameters of the cavity  
(for the fundamental $TM_{010}$ mode)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonant frequency, MHz</td>
<td>$f_0$</td>
<td>180.4</td>
</tr>
<tr>
<td>Frequency tuning range, kHz</td>
<td>$\Delta f_0$</td>
<td>320</td>
</tr>
<tr>
<td>Quality factor</td>
<td>$Q$</td>
<td>40000</td>
</tr>
<tr>
<td>Shunt impedance, MOhm</td>
<td>$R = \frac{U^2}{2P}$</td>
<td>5.3</td>
</tr>
<tr>
<td>Characteristic impedance, Ohm</td>
<td>$\rho = \frac{R}{Q}$</td>
<td>133.5</td>
</tr>
<tr>
<td>Operating gap voltage amplitude, MV</td>
<td>$U$</td>
<td>0-1.1</td>
</tr>
<tr>
<td>Power dissipation in the cavity, kW, at $U=1100$ kV</td>
<td>$P$</td>
<td>115</td>
</tr>
<tr>
<td>Input coupler power capability, kW</td>
<td>$P_{in}$</td>
<td>400</td>
</tr>
</tbody>
</table>
2 MeV injector

MS : focusing solenoid  MXY : steering magnet  BDCM : beam current monitor

BPM : bean position monitor  BWBM : wall current monitor  RFC : RF cavity
2 MeV injector parameters

- Bunch repetition rate, MHz: up to 22.5
- Charge per bunch, nC: 2
- Start bunch length, ns: 1.2
- Final bunch length, ns: 0.1
- Final energy, MeV: 2
2 MeV injector
Bent and injection beamline
First-stage ERL: machine parameters

- Bunch repetition rate, MHz 11.2
- Average electron current, mA 20
- Maximum energy, MeV 12
- Bunch length, ps 100
- Normalized emittance, mm*mrad 30
### Undulator parameters (one section)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length, m</td>
<td>4</td>
</tr>
<tr>
<td>Period, mm</td>
<td>120</td>
</tr>
<tr>
<td>Number of periods</td>
<td>32</td>
</tr>
<tr>
<td>Gap, mm</td>
<td>80</td>
</tr>
<tr>
<td>Undulator parameter K</td>
<td>0 - 1.2</td>
</tr>
</tbody>
</table>
Undulators and accelerating RF cavities
Optical beam sizes (mm) vs. distance along the beamline (m)
Experimental stations
# Free electron laser Parameters

- **Wavelength, mm**: 0.12-0.18
- **Pulse duration, FWHM, ps**: 70
- **Pulse energy, mJ**: 0.04
- **Repetition rate, MHz**: 5.6 or 11.2
- **Average power, kW**: 0.4
- **Minimum relative linewidth, FWHM**: $3 \cdot 10^{-3}$
THz images
High average power of radiation (up to 400 W) in combination with high peak power (up to 1 MW) enables performing high power density experiments.

Laser beam focused in the atmosphere with a parabolic mirror (f=1.0 cm) ignites a continuous optical discharge.

Unfocused laser beam drills an opening in 50-mm plexiglas slab within three minutes (ablation without burning).

These phenomena can be used for many fundamental and applied experiments (plasma physics, aerodynamics, chemistry, material processing and modification, biology...).
Ablation of stone
Ultra-soft laser ablation of DNA

Demonstration of ultra-soft ablation of DNA samples without denaturation: when the power density of THz radiation is optimal, particle size spectra contain only the peaks corresponding to the initial particles. For higher power densities multi-peak spectra are observed.
Full-scale energy recovery accelerator and FEL

A full-scale 4-track energy recovery accelerator uses the same accelerating structure as the 1st stage ERL, but, in contrast to the latter, it is placed in the horizontal plane. Thus, the possibility to run the old FEL remains.

The choice of operation regime at one of two machines and one of three FEL will be achieved by simple reswitching of the bending magnets.
First stage ERL and FEL
Full-scale accelerator and FELs

Four tracks in horizontal plane with two IR FELs (under construction)

Common for all FELs accelerating system (exists)

One track in vertical plane with terahertz FEL (exists)
# Full-scale FEL parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron beam energy, MeV</td>
<td>40</td>
</tr>
<tr>
<td>Number of orbits</td>
<td>4</td>
</tr>
<tr>
<td>Maximum bunch repetition rate, MHz</td>
<td>90</td>
</tr>
<tr>
<td>Beam average current, mA</td>
<td>150</td>
</tr>
<tr>
<td>Wavelength range, micron</td>
<td>5-240</td>
</tr>
<tr>
<td>Maximum output power, kW</td>
<td>10</td>
</tr>
</tbody>
</table>
Scheme of the electron outcoupling for the second stage of the Novosibirsk FEL

1 and 2 – mirrors of optical resonator; 3, 4, and 5 – undulators; 6 – 45-degree mirror; 7 – radiation output.
Conclusions

• First stage machine operates stably.
• Several user stations are in operation.
• Some optical experiments were performed.
• The work to increase the average power is continuing.
• The manufacturing of the second stage of FEL is in progress. Commissioning is expected in 2007.