Status of FIR undulator for TTF, Phase 2

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Objectives:

- Pump-probe facility combining X-ray SASE FEL radiation and powerful, coherent far infrared radiation.
- Nondestructive electron beam diagnostic allowing to reconstruct bunch profile at a femtosecond-scale resolution.
Potential Upgrade of the FEL User Facility at DESY

VUV/X-ray FEL
\( \lambda = 6-100 \text{ nm} \)

2nd/3rd Harmonic Generation
Wavelength down to 2nm

--- Under Construction
--- Potential upgrade

Pump-probe Facility

Conventional laser system
\( \lambda = 750-900 \text{ nm} \)

FIR Coherent Source
\( \lambda = 100-400 \text{ \mu m} \)

Regenerative FEL Amplifier
\( \lambda = 200-400 \text{ nm} \)

Femtosecond X-ray Source
Pulse duration down to 10 fs
\( E_{ph} = 10-50 \text{ KeV} \)
\( 10^7 \text{ photon/pulse} \)
\( B = 10^{13} \text{ ph./sec/mm}^2/\text{mrad}^2/(0.1\% \text{ band.}) \)
Properties of the undulator radiation

- The radiation power, averaged over an ensemble:

\[ \langle P(\omega) \rangle = p(\omega)[N + N(N - 1)|\tilde{F}(\omega)|^2] , \]

\( p(\omega) \) is the radiation power from single electron.

- Angular dependence of the radiation frequency of the undulator radiation:

\[ \omega = 2ck_w\gamma^2 \left[ 1 + \frac{K^2}{2} + \gamma^2\theta^2 \right]^{-1} . \]

- Radiation within the cone of half angle

\[ \theta_{\text{con}} = \frac{\sqrt{1 + K^2/2}}{\gamma\sqrt{N_w}} \]

has relative spectral bandwidth \( \Delta \omega/\omega \simeq 1/N_w \).

- The energy radiated into the central cone by a single electron:

\[ \Delta \mathcal{E}_{\text{con}} \simeq \pi e^2 A_{\parallel}^2 \omega_0 K^2 / [c(1 + K^2/2)] \]

- The coherent radiation enhances the energy radiated into the central cone by a factor of \( N|\tilde{F}(\omega_0)|^2 \).
FIR coherent radiation source at the TESLA Test Facility

Electron beam
- Energy: 400-1000 MeV
- Number of electrons per bunch: $6 \times 10^9$
- rms bunch length: 50 $\mu$m
- rms normalized emittance: $2\pi$ mm·mrad
- rms (VUV FEL induced) energy spread: 2.5 MeV
- Number of bunches per train: 7200
- Repetition rate: 10 Hz

Undulator
- Type: Planar
- Period: 40 cm
- Peak magnetic field: 0–1.2 T
- Number of periods: 10

Output radiation (into central cone)
- Wavelength: 50–300 $\mu$m
- Bandwidth: Transform-limited
- Peak power: 1–50 MW
- Average power: 1–50 W
- Micropulse duration (rectangular profile): 2–10 ps
- Micropulse energy: 0.1–0.4 mJ
- Bunch spacing: 111 ns
FIR coherent source at TTF (Phase 2)
FIR undulator at the TESLA Test Facility

Type: planar, electromagnetic
Number of poles                      10
Period length                       40 cm
Total length                         430 cm
Peak magnetic field             0-1.2 T
Power supply for FIR undulator at the TESLA Test Facility

HERA power supply MK 506/4
(available on stock)
1. Iron yoke
2. Support structure.
3. Basic coil.
4. End coil.
5. Column
6. The device for an alignment

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Note: The sizes are for information.
Bunch profile at the TESLA Test Facility
(particle tracking and fitting of bunch profile)

\[ I(t) \simeq I_0 \exp \left( -\frac{t^2}{2\tau_0^2} \right) \quad \text{for} \quad t_1 > t > -\infty ; \]
\[ I(t) \simeq \frac{A \exp(-t/\tau_1)}{\sqrt{(t + t_0)/\tau_1}} \quad \text{for} \quad t > t_1 > 0 . \]
Bunch profile at the TESLA Test Facility
(particle tracking taking into account space charge and CSR)

\[ I(t) \simeq I_0 \exp \left( -\frac{t^2}{2\tau_0^2} \right) \quad \text{for} \quad t_1 > t > -\infty ; \]

\[ I(t) \simeq \frac{A \exp(-t/\tau_1)}{\sqrt{(t + t_0)/\tau_1}} \quad \text{for} \quad t > t_1 > 0 . \]
Measurement of bunch form-factor

\[ \Delta W_{\text{CSR}} \simeq \frac{\pi e^2 A_j^2 \omega_0 K_w^2}{c(1 + K_w^2/2)} N^2 |F(\omega_0)|^2 \]
Reconstruction of bunch profile

\[ I(t) \simeq I_0 \exp \left( -\frac{t^2}{2\tau_0^2} \right) \quad \text{for} \quad t_1 > t > -\infty ; \]

\[ I(t) \simeq \frac{A \exp (-t/\tau_1)}{\sqrt{(t + t_0)/\tau_1}} \quad \text{for} \quad t > t_1 > 0. \]

Time constant t1 should be taken from streak camera measurements.
Conclusion

✓ Measurements of coherent undulator radiation provide an ideal tool for determination of bunch form-factor with high accuracy.
✓ Combination of these measurements with streak camera measurements, and application of deconvolution technique allows one to reconstruct bunch profile even for the case of strongly non-gaussian shape.
✓ Implementation of this technique at TTF can be realized in a cost effective way.