Status of THz spectroscopy as a standard diagnostic method.

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Overview

1 Introduction
   Used radiation
   Present monitors at FLASH

2 Single shot IR spectrometer

3 Spectroscopy as bunch compression monitoring
   Spectra
   Behavior at phase variations
   SASE - CTR intensity correlation

4 Longitudinal profile reconstruction
   Method
   Examples

5 Activities (Big Shutdown)
   New spectrometer
   Spectroscopy with 3rd harmonic cavity

6 Conclusions
Transition radiation

Ginzburg-Frank-Formula:
\[
\frac{d^2 U}{d\omega d\Omega} \bigg|_{e^-} = \frac{e^2}{4\pi^3 \epsilon_0 c} \cdot \frac{\beta^2 \sin^2 \theta}{(1 - \beta^2 \cos^2 \theta)^2}
\]

Consideration of electron ensemble:
\[
\frac{d^2 U}{d\omega d\Omega} \bigg|_{\text{bunch}} = \frac{d^2 U}{d\omega d\Omega} \bigg|_{e^-} \cdot \left( N + N(N - 1) \cdot |F(\omega)|^2 \right)
\]

Coherent part dominates + small transverses dimensions:
\[
\frac{d^2 U}{d\omega d\Omega} \bigg|_{\text{bunch}} \approx \frac{d^2 U}{d\omega d\Omega} \bigg|_{e^-} \cdot N^2 \cdot |F_{\text{long}}(\omega)|^2
\]

Radiation emitted in small cone of $2/\gamma$:
\[
\frac{dU}{d\omega} \bigg|_{\text{bunch}} \approx \frac{dU}{d\omega} \bigg|_{e^-} \cdot N^2 \cdot |F_{\text{long}}(\omega)|^2
\]
Formfactor

\[ F_{\text{long}}(\lambda) = \int dz \, \rho_{\text{norm}}(z) \cdot \exp(-2\pi i z \cdot \lambda^{-1}) \quad \text{with} \quad \int dz \, \rho_{\text{norm}}(z) = 1 \]
incoherent spectral energy – finite screen (d=40mm)

\[ \text{spectral energy} = \frac{\text{pJ} \cdot \mu\text{m}^{-1} \cdot \text{nC}^{-1}}{\gamma = 1000} \]

Extension to finite screen sizes:

**TR** finite full screen → cutoff at long wavelengths

**DR** hole in screen → damping smaller wavelengths

→ TR is recommended for small structures!
Compression monitor

Coherent diffraction monitor:
- parasitic detection (non destructive)
- integrated energy measured via pyroelement
- cut-off wavelength at 80 µm (window)

→ empirical value on which phase of ACC1/ACC23 is regulated

CDR monitor behind BC2
Setup I

**Intention:**
Do broadband spectroscopy of CTR from compressed electron bunches.
Broadband single shot grating spectrometer. Developed by H. Delsim-Hashemi.

Characteristics:

- 3 staged reflective blazed gratings (filter + 2 dispersive elements)
- Focussing ring mirrors
- 2 × 30 pyro detectors
- 3 grating combinations (3 µm up to 65 µm)
- Limit of $|F| = 0.001$ at 1 nC
- Experimental setup to establish method

Last spectrometer configuration used (S. Wesch)
FEL spectrum

FEL bunch spectrum at 700MeV – 3 × 330 shots

- coherent radiation down to spectrometer limit
- strong fluctuations due to machine stability
Spectrum BC3 only

bunch spectrum – BC2 off / BC3 on – $\phi_{\text{ACC23}} = -30^\circ$ – 3 × 120 shots

- enhancement of intensity at short wavelengths
- fluctuations on lower level
Behavior at phase variations

- extremely strong dependence near SASE condition (sharpness not understood)
  → setpoint to monitor compression

- phase independent radiation (microbunching)
  → complicates profile reconstruction
- maximum SASE intensity shifted about $\Delta \phi_{\text{ACC1}} = 0.6^\circ$ with respect to maximum CTR signal

→ @140m compression is not completed (dogleg)

→ position not ideal to correlate SASE with spectrum
Reconstruction method

Spectroscopy indirect method of measuring the longitudinal shape of bunch.

→ determination of $|F|$, but phase information gets lost!
Example I
longitudinal formfactor BC2 off, $\phi_{\text{ACC23}}=-30^\circ$

$|F_{\text{long}}|$ vs. $\lambda$ [$\mu$m]

$\sigma_{\text{SPIKE}} \sim 5.6 \pm 0.2 \mu$m (FWHM)
Engineered and improved version of spectrometer.

Characteristic:
- 4 stages
- 2 grating combinations
  → spectral range 2 µm - 200 µm
- 120 pyros
- motorized beam alignment
- more compact

Additional new location:
- in front of 1st undulator
- uses same (O)TR station as LOLA

CAD picture (Courtesy K. Ludwig)
Outlook to formfactor of bunch

simulation I. Zagorodnov

location of minima determines bunch length
Conclusions

2 stage spectrometer (prototype):
   i. bunch profile construction $\rightarrow$ spike width in $\mu m$ range.
   ii. extensively used for microbunch studies
   iii. not ideal to correlate SASE with spectra (dogleg)
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engineered 4 stage spectrometer:
   I. spectrometer leaves \textit{experimental} status
   II. larger spectral range
   III. additional location in front of undulators