Study of Coherence limits and chirp control in long pulse FEL oscillator

Y. Socol, A. Gover, A. Eliran, M. Volshonok, Y. Tel Aviv University
Pinhasi, B. Kapilevich, A. Yahalom, Y. Lurie, M. Kanter, M. Einat B. Litvak
The College of Judea and Samaria, Ariel
Inner Cavity Electrostatic Accelerator FEL Configuration

thermionic e-gun

SP₁

Vacuum tube

Gas tank

Resonator

Injector acceleration focus and interaction deceleration collector
The Israeli FEL
Coherence Limits of FEL

Schawlow–Towns Equivalent Natural linewidth*:

\[
\Delta f_{\text{laser}} = \frac{(\Delta f_{1/2})^2}{I_0/e}
\]

\[
(\Delta f_{\text{laser}} = 10^{-2} \text{ Hz, for } I_0 = 2A, \Delta f_{1/2} = 10 \text{MHz})
\]

Technical noise frequency instability**:

\[
\Delta f_{\text{tech}} = \left[ \left( \frac{\partial \phi}{\partial V_b} \right)^2 \langle (\Delta V_b)^2 \rangle + \left( \frac{\partial \phi}{\partial I_b} \right)^2 \langle (\Delta I_b)^2 \rangle \right] \Delta f_{1/2} \quad (\phi = \delta k_r L_w)
\]

\[
\frac{\Delta f_{\text{tech}}}{f_0} = 5 \cdot 10^{-7} \quad (\text{for } \Delta V_{brms} = 1kV, \Delta I_{brms} = 10mA)
\]

* A. Gover, A. Amir, L.R. Elias, PR A, 35, 164 (1987)

Effect of Voltage Drop: Mode Hopping

Gain

1/R (Loss Line)

\( f_0 \)

\( f_{m1} \)

\( f_{m2} \)

\( f_{\text{max}} \)
Effect of Voltage Drop: Chirp

\[ f(t) - f_m = (f_{\text{max}}(t) - f_m) \frac{\Delta f_{1/2}}{\Delta f} \]

\[ \frac{df(t)}{dt} = \frac{df_{\text{max}}}{d\gamma} \frac{d\gamma}{dt} \frac{\Delta f_{1/2}}{\Delta f} \]
FEL Frequency Dependence on in a Waveguide Dispersive

For $f_{\text{max}} = 86\text{GHz}$, $\Delta f = 6\text{GHz}$, $\Delta f_{1/2} = 16\text{MHz}$

$$\frac{df_{\text{max}}}{dV} = 0.43 \frac{\text{MHz}}{\text{KV}} \quad \frac{dV}{dt} = 0.7 \frac{\text{KV}}{\mu s} \Rightarrow$$

$$\frac{df}{dt} = 0.3 \frac{\text{MHz}}{\mu s}$$
Block-Diagram RF Measurements of FEL Radiation

- From FEL
- Local Oscillator
- Coupler 10 dB
- Mixer
- IF Detector
- Detector
- Collector current
- E-gun grid Pulse
- Ch 1
- Ch 2
- Ch 3
- Ch 4

\[ f_{IF} = |f - f_{LO}| \]
Voltage Drop Effect: Mode Hoping

IF - signal

Numerically filtered IF signal amplitude
IF Signal at Single Mode Operation
Measured IF Signal

\[ f_{IF} = |f(t) - f_{LO}| \]

\( f(t) > f_{LO} = 86,4000 \, [MHz] \)

\( f(t) < f_{LO} = 86,402 \, [MHz] \)

\[ f(0) = 86.401 \pm 1 \, [MHz] \]
Frequency Chirp and Power Decay of a single mode during voltage drop

Measured

FEL3D Oscillator Simulation
Spectrum and Inherent Spectral Width

1 µs window spectrogram

10 µs window spectrogram after numerical elimination of linear chirp
Inherent Spectral Width

The inherent spectral width is 0.2 MHz.
Planned Application of Controlled Chirp in Electrostatic Accelerator FEL

thermionic e-gun

SP₁

Vacuum tube

Gas tank

Resonator

Q₁-Q₄

wiggler

Q₅-Q₈

V(t)

Injector

acceleration

focus and interaction

deceleration

collector

e-beam

PS₂
Scanning Single Pulse Spectroscopy

\[ \Delta f_{\text{inh}} = \frac{1}{t_p} (0.01 \text{MHz}) \]

\[ \Delta f_{\text{chirp}} = \frac{f_{\text{max}} - f_0}{\Delta f} \Delta f_{1/2} (5 \text{MHz}) \]

Transmission of Absorption Line
FEL Oscillator Frequency Stabilization

Acceleration tube

Optical receiver

wiggler

f_{LO}

f_{FEL}

mixer

Phase detector

V_B

G

V_{cont}

V_{cont}

Fiber
Conclusion

1. \( \frac{df}{dt} = 0.3 \frac{MHz}{\mu s} \)

2. \( \left( \frac{\Delta f}{f} \right)_{\text{intrinsic}} = 2 \cdot 10^{-6} \)

3. Plans to utilize chirp for :
   (a) Single pulse scanning spectroscopy
   (b) Phase locked loop frequency stabilization