The beamlet method

Methods to improve FEL output from “dirty” beams

James Henderson, Lawrence Campbell and Brian McNeil
Outline

- Motivation Plasma accelerators
- Potential beamlet solution modulate and disperse
- Chicanes to maintain resonant interaction
- Simplified Model
- The beamlet method
- Conclusion
Motivation

- Plasma accelerators have accelerating gradients of $10^3$ greater than conventional accelerators, potential for “table top” FELs.

Image credit - https://www2.physics.ox.ac.uk/research/plasma-accelerators
Front page image – http://lpap.epfl.ch/page--en.html
Motivation

- Plasma accelerators have accelerating gradients of $10^3$ greater than conventional accelerators, potential for “table top” FELs.
- However, electron pulses from plasma accelerators typically have a large energy spread.

For an FEL we require

$$\frac{\sigma_\gamma}{\gamma_r} < \rho$$

where

$$\rho = 10^{-2}$$

A method of determining narrow energy spread electron beams from a laser plasma wakefield accelerator using undulator radiation

J. G. Gallacher, et. al. PHYSICS OF PLASMAS 16, 093102 2009
Potential Solution

- Beamlet method – based on EEHG technique
- Electron Pulse is modulated and then dispersed
Chicanes

Pass radiation between beamlets using a undulator-chicane lattice

\[ \bar{s} = \bar{l} + \bar{\delta} \]

\[ \frac{\Delta \omega}{\omega_r} = \frac{4\pi \rho}{\bar{s}} \]
Real Beamlets
Simplified Model

Approximating the beamlets

Front of light pulse

Electrons slip backwards in the chicane

Window in light frame

Units of cooperation length

-electrons

\((\gamma - \gamma_c)(\rho_0)\)

\(\overline{z}_f\)
Simplified Model

The modes are locked by equating modes from the undulator-chicane lattice and the resonant frequency difference of the beamlets.

\[
\frac{\Delta \omega_{\text{beamlet}}}{\omega_r} = 2 \frac{\Delta \gamma}{\gamma_r} \quad \quad \frac{\Delta \omega_{\text{modal}}}{\omega_r} = \frac{4\pi \rho}{\bar{s}} \quad \quad \Delta \omega_{\text{modal}} = \Delta \omega_{\text{beamlet}}
\]
Potential Solution

- Electron pulses with a large energy chirp exhibit an energy dependent slippage

\[ \bar{s}_\gamma = 2 \left( \frac{\gamma_r - \gamma_j}{\gamma_r} \right) (\bar{l} + D) + \bar{s} \]

- Electron of different speeds will take different paths from undulator and chicane
- Can lead to mismatching when passing radiation from beamlet to beamlet
The beamlet method \((D=0)\)*

Mode-locked beamlet modes

\[
\bar{s} = 2.51, \bar{l} = 0.25, \bar{\delta} = 2.26, D = 0
\]

\[
\frac{\Delta \omega}{\omega_r} = \frac{4 \pi \rho}{\bar{s}}
\]

* James Jones’ Ref
The beamlet method \((D>0)\)

\[
\bar{s} = 2.51, \bar{l} = 0.25, \bar{\delta} = 2.26, \boxed{D = 0.3}
\]

\[
\bar{s}_\gamma = 2 \left( \frac{\gamma_r - \gamma_j}{\gamma_r} \right) (\bar{l} + D) + \bar{s}
\]
The beamlet method (D=0)

\[ \frac{\Delta \omega}{\omega_r} = \frac{4\pi \rho}{\bar{\delta}} \]

\[|A|^2\]

\[\bar{s} = 2.51, \bar{l} = 1.88, \bar{\delta} = 0.63, D = 0\]

\[ \bar{s}_\gamma = 2 \left( \frac{\gamma_r - \gamma_j}{\gamma_r} \right) (\bar{l} + D) + \bar{s} \]
The beamlet method

- Electron Pulse is modulated and dispersed
The beamlet method
The beamlet method

No Beamlets
Intensity at $\tilde{z} = 30.1593$

Beamlets
Intensity at $\tilde{z} = 30.1593$
Conclusion

• Method to improve the FEL output was presented
• This is on-going research
• Results so far are promising with two-three order magnitude improvement

Future development

• Optimization of the beamlet parameters
• Using a taper to cancel out the beamlet chirp
• Use of these techniques for multi electron pulse schemes
Thanks for listening.
Any questions?
Mode generation

For continued slips of distance $s$, only those wavelengths with an integer number of periods in distance $s$ will survive after many such slips. For $s$ an integer of $\lambda_j$:

$$s = N\lambda_j = (N+1)\lambda_{j-1}$$

$$\Rightarrow \omega_j = \frac{2\pi c N}{s} ; \omega_{j-1} = \frac{2\pi c (N+1)}{s} \Rightarrow \Delta \omega_s = \omega_{j-1} - \omega_j = \frac{2\pi c}{s}$$
Mode generation

For continued slips of distance $s$, only those wavelengths with an integer number of periods in distance $s$ will survive after many such slips. For an integer of $j$:

\[ \frac{2\pi c}{s} \]

The spectrum is the same as a ring cavity of length $s$. A ring cavity of length equal to the total slippage in each undulator/chicane module has been synthesized.
The beamlet method

U-CD-U-CS - special undulator-chicane modules
U – undulator
CD – dispersion only chicane
CS – slippage only chicane

\[ \frac{\Delta \omega}{\omega_r} = \frac{4\pi \rho}{\delta} \]
The beamlet method

\[ \frac{\Delta \omega}{\omega_r} = \frac{4\pi \rho}{\bar{s}} \]

\[ \bar{s} = 2.51, \bar{l} = 1.88, \bar{\delta} = 0.63, D = -1.88 \]

\[ \bar{s}_\gamma = 2\left(\frac{\gamma_r - \gamma_j}{\gamma_r}\right)(\bar{l} + D) + \bar{s} \]
The beamlet method

- Electron pulses with a large energy chirp exhibit an energy dependent slippage

\[ \bar{s}_\gamma = 2\left( \frac{\gamma_r - \gamma_j}{\gamma_r} \right)(\bar{l} + D) + \bar{s} \]

- These electrons take a shorter path through the undulator than lower energy electrons

- Can lead to mismatching when passing radiation from beamlet to beamlet
Potential Solution