Applying Transverse Gradient Undulators to Suppression of Microbunching Instability (TUPLR001)

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Theoretical Analysis

- Transverse Gradient undulator (TGU) is a functional device which is able to manipulate the electron beam through transverse-to-longitudinal phase space coupling.

- The TGU provides two ways to mitigate the microbunching instability (*μBI*): increasing the uncorrelated energy spread of a *linearly chirped* beam *and* introducing the longitudinal mixing from *transverse spread*.

- The TGU *introduces the transverse emittance growth*, which can be corrected by *adding another TGU* on the other side of the bunch compressor. And the extra uncorrelated energy spread can also be compensated by the 2nd TGU.

The final gain of *μBI* with TGUs included:

$$G_f \approx G_0 \exp\left(-\frac{k^2 R_{56}^2 \sigma_\gamma'^2}{2\gamma_0^2}\right) \exp\left[-\left(\frac{k^2\tau^2\sigma_x^2}{2} + \frac{k^2\tau^2 L_T^2 \sigma_{x'}^2}{8}\right)\right]$$

where $\tau = L_T K_0^2 \alpha (2\gamma^2)^{-1}$ is defined as the gradient parameter of TGU, and

$$\sigma_\gamma' = \sqrt{\sigma_\gamma^2 + (h\tau\gamma_0\sigma_x)^2 + (h\gamma_0\sigma_{x'}\tau L_T/2)^2}$$

is the rms uncorrelated energy spread of the beam at the exit of the TGU, L_T is the length of the TGU, τ is the TGU strength, and $G_0 = k|R_{56}|I_0 Z(k)(\gamma_0 I_A Z_0)^{-1}$, $Z_0 = 377\Omega$ is the free space impedance.

Simulation results

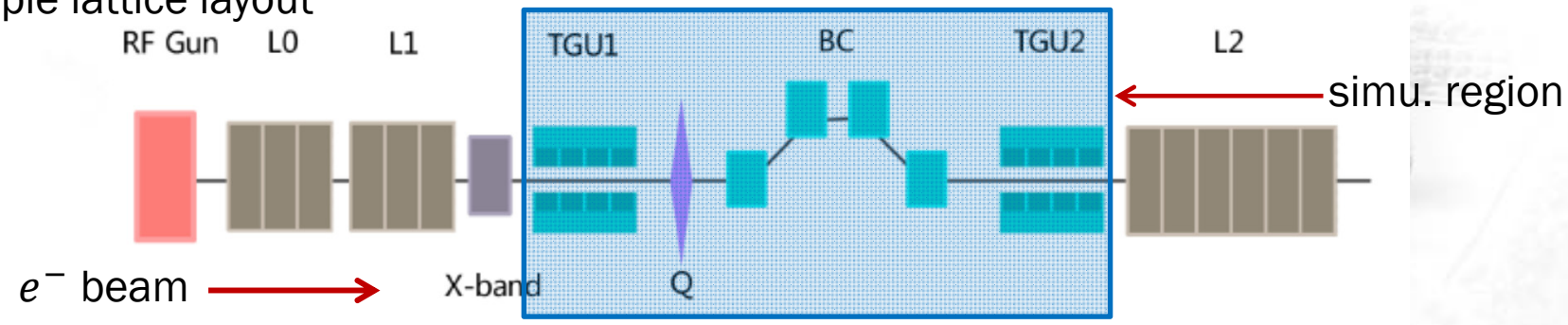
2-D transport matrix of TGU

$$\mathbf{R}_{TGU} \approx \begin{pmatrix} 1 & L_T & 0 & \tau L_T / 2 \\ 0 & 1 & 0 & -\tau \\ \tau & \tau L_T / 2 & 1 & -\tau^2 L_T / 6 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

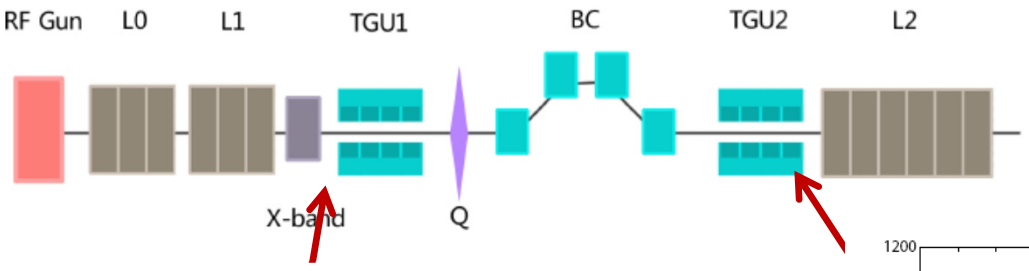
ELEGANT simulation

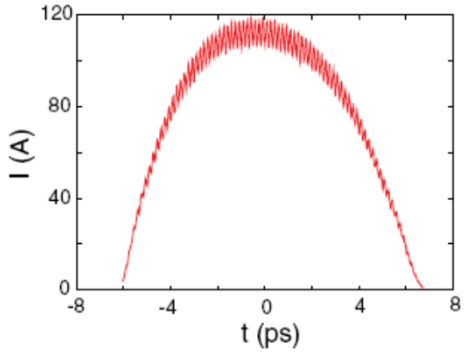
Parameters	Value
Bunch charge (nC)	1
Beam energy before compression (MeV)	245
Bunch length (FWHM) before compression (ps)	7
Compression ratio	9
Peak beam current before BC (peak)	110
rms uncorrelated slice energy spread before BC (keV)	3
Amp. Of current modulation (peak-to-peak)	10%
Number of macro-particles in simulation	10 million

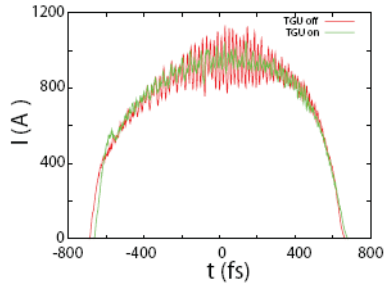
Example lattice layout



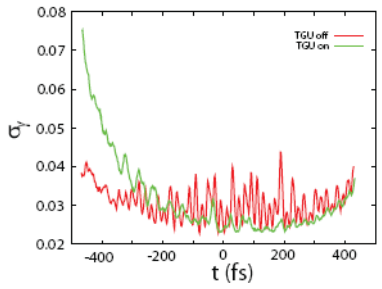
Simulation results







(a) Longitdudinal beam current profile at the exit of TGU2



(b) Slice energy profile of the central part of the beam at the exit of TGU2

- Initial beam current profile with 10% peak-to-peak modulation.

- Horizontal emittance goes from 0.98 μm to 1.07 μm, the growth mainly comes from nonlinear effects such as CSR, LSC etc.

- Longitudinal beam current (upper) and slice energy profile (lower) at the exit of TGU2 with TGUs on (green) and off (red).

Conclusions

- TGU is able to suppress the instability by two factors: the additional slice energy spread and the longitudinal mixing from the transverse spread without changing the direction of the beam propagation.

- By applying two TGUs symmetrically before and after the bunch compressor, the microbunching instability can be effectively suppressed and the beam quality can also be restored very well after all by carefully chosen parameters.

- Because the TGU scheme does not need external RF power, laser and chicane systems, etc., it has the advantages over the other ones in terms of high efficiency, less complexity and better jitter tolerance. As a novel method, the TGU scheme opens up a new way for us to improve the performance of the x-ray free-electron laser, and can be a good candidate for the microbunching instability control in addition to a laser heater.

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