Tapered Flying Radiofrequency Undulator

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Abstract

We propose an efficient XFEL consisting of sequential RF undulator sections using: 1) tapered flying RF undulators, 2) short pulse, high peak-power RF and 3) driving undulator sections by spent electron beam. In a flying RF undulator, an electron bunch propagates through a high-power, nanosecond, co-propagating RF pulse. Helical waveguide corrugation supports a space harmonic with a negative propagation constant, providing a large Doppler up-shift. The undulator tapering technique improves FEL efficiency by 1-2 orders of magnitude in comparison with other facilities by decreasing the undulator period so that particles are trapped in the combined field of the incident x-ray and undulator field. We develop a so-called non-resonant trapping regime not requiring phase locking for feeding RF sources. Simulations show that by decreasing the corrugation periodicity one can vary an equivalent undulator period by 15%. The spent electron beam can be used to produce wakefields that will drive the RF undulator sections for interaction with the following beam. We have already manufactured and tested the 30 GHz simplified version of the 50 cm long undulator section for cold measurements.

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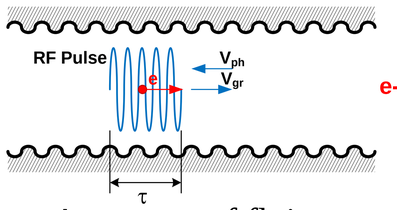
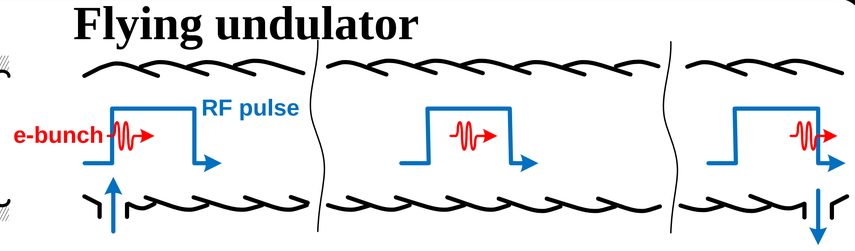
Flying undulator

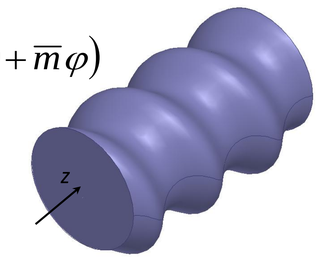


A concept of flying RF undulator



Flying RF undulator geometry (helical corrugation) and interaction timing structure.

$$r(z,\varphi) = R_0 + a\cdot\sin\left(2\pi z/D + \overline{m}\,\varphi\right)$$

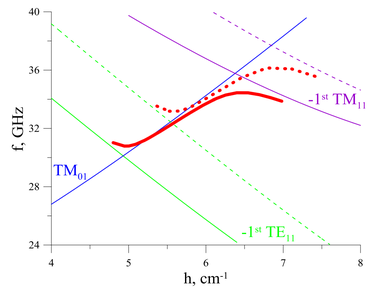


$$h_n = h_0 + \frac{2\pi\cdot n}{D}$$

$$h_0 > 0,\ \ h_{-1} < 0, v_{gr} = \frac{\partial\omega}{\partial h_0} > 0.$$

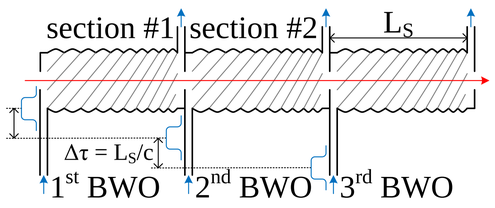
$$\lambda_u = 2\pi/(|h_{-1}| + k)$$

Effective period of ndulator

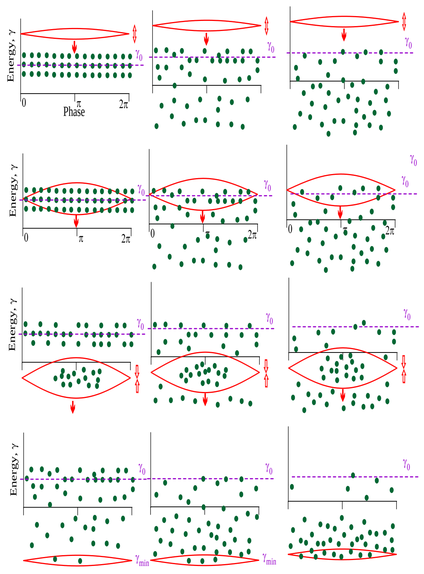


Dispersion of the operating mode (red solid) of the helical undulator with period of corrugation 6 mm and dispersion of this mode (red dashed) of the undulator with period of corrugation 5.4 mm.

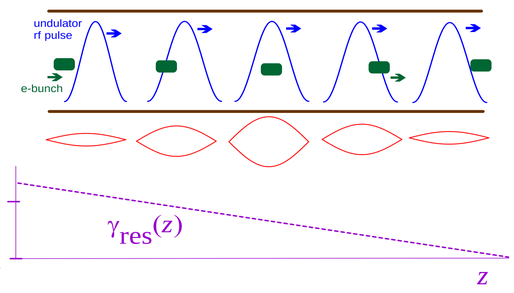
Tapered flying undulator



FEL scheme based on tapered RF undulators with decreasing equivalent undulator period.

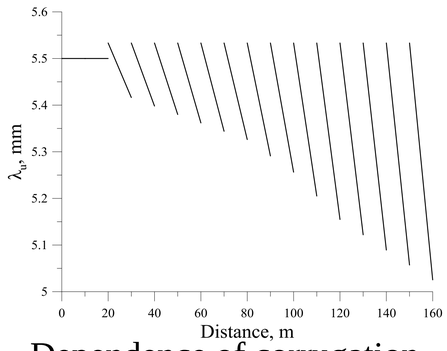


Phase-energy distribution of particles during the passage of three sections of FEL.

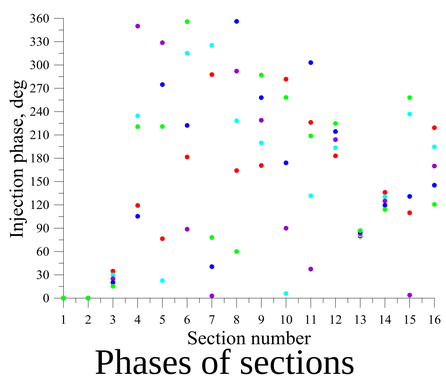


The motion of the bunch relative to the microwave pulse within one section and the change in particle energy due to radiation.

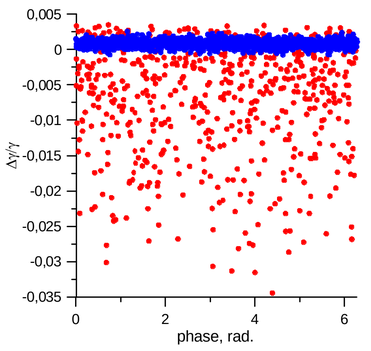
Parameters:	
Bunch energy	600 MeV
X-ray wavelength	2 nm
Charge	100 pC
Bunch length	0.17 ps
Bunch diameter	30 μm
Energy spread	0.1%
Section length	10 m
Number of sections	16
K_{max}	0.25



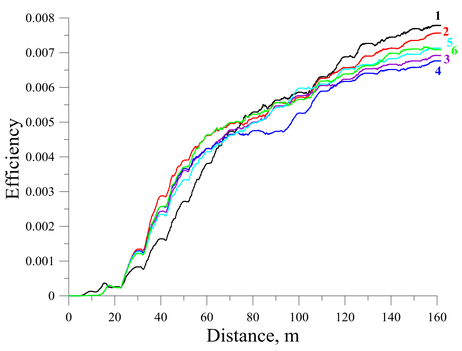
Dependence of corrugation period in FEL consisted of individually tapered sections.



Phases of sections

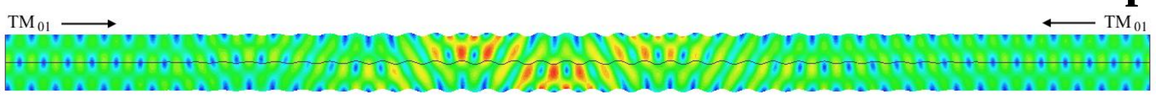


Energy-phase distribution of particles in entrance of FEL (blue) and in exit (red).

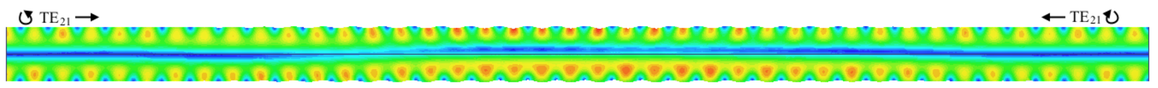


Efficiency of lasing along FELs for in-phase undulator sections (black curve#1) and for 5 different sets of sections with randomly distributed phases (curves 2-6).

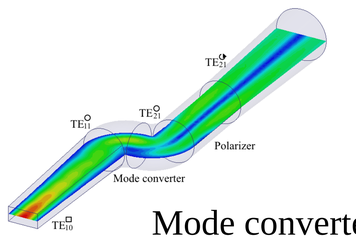
Low power tests



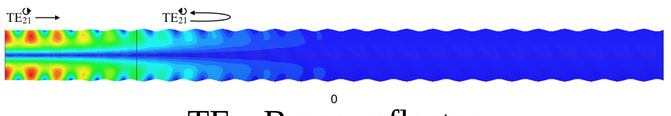
TM_{01}-TM_{11} undulator standing wave



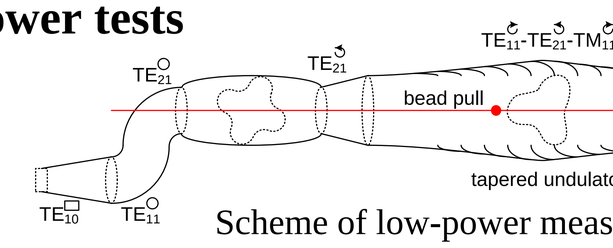
TE_{21}-TM_{11} undulator standing wave



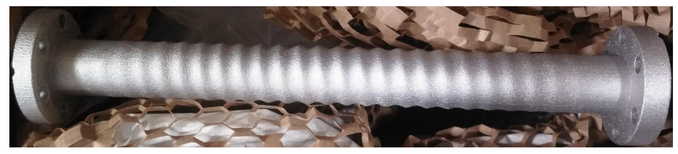
Mode converter



TE_{21} Bragg reflector



Scheme of low-power measurements.



A 34 GHz TE11-TM01-TM11 RF undulator.