Helical Waveguides for Short Wavelength Accelerators and RF Undulators

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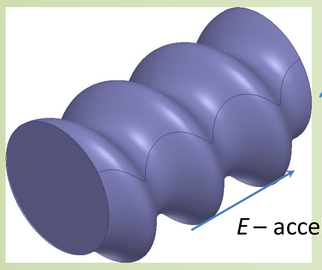
Abstract

The short wavelength accelerating structure can combine properties of a linear accelerator and a damping ring simultaneously. It provides acceleration of straight on-axis beam as well as cooling of this beam due to the synchrotron radiation of particles. These properties are provided by specific slow eigen mode which consists of two partial waves, TM01 and TM11.

The flying RF undulator introduces a high-power short pulse, propagating in a long helically corrugated waveguide where the -1st space harmonic with negative phase velocity is responsible for particle wiggling. High group velocity allows providing long interaction of particles with RF pulse. Calculations show that RF undulator with period 5 mm, undulator parameter 0.1 is possible in 1 GW 10 ns pulse at frequency 30 GHz. These RF parameters, as it was shown experimentally, are achievable by means of the relativistic BWO.

The eigen mode in a helical undulator might be slow one so that the 0th harmonic phase velocity is equal to light velocity. Such wave (with non-zero longitudinal electric field) can be excited by relativistic drive bunch in a waveguide where witness bunch follows after the drive bunch, wiggles in wakefield of the drive bunch, and generates X-rays at whole waveguide length. Helical waveguides can also be used in order to channel low-energy bunches (due to longitudinal focusing field) in RF undulator of THz FEL.

Helical Accelerating Structure



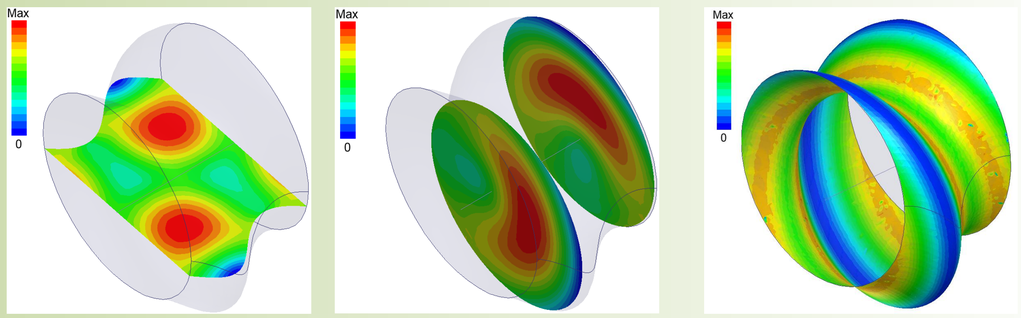
$$r(z,\varphi) = R + a\cdot\sin\left(\frac{2\pi\cdot z}{P} + \varphi\right)$$

transverse field components
(far from Cherenkov synchronism)

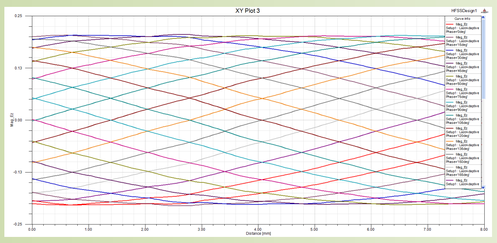
E – accelerating field (synchronous with particles)

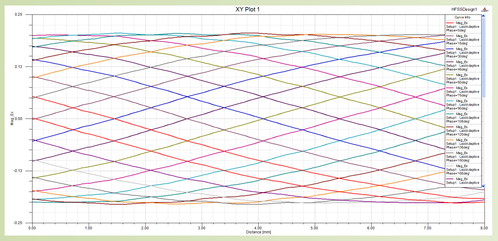
Appealing features:

1. Non-synchronous transverse field components might provide: 1) emittance control (beam cooling due to synchrotron radiation of particles); 2) soft near axis beam focusing
2. A new structure has smooth shape of constant circular cross-section (no expansions or narrowings) and big aperture (no small irises)
3. A new technology of the mass production seems possible which allows avoiding junctions inside long accelerating section

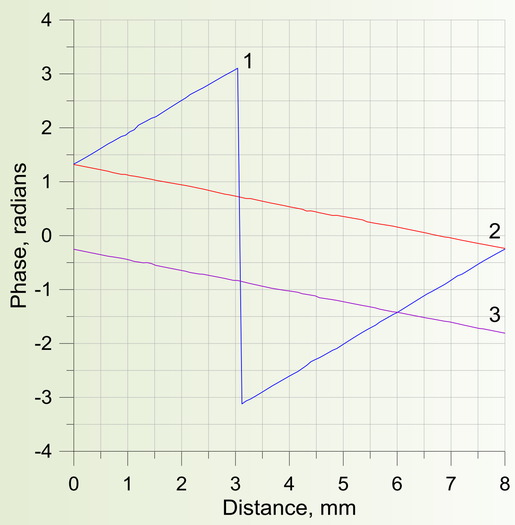


Module of electric field in middle plane, in two sequent cross-sections and on the surface.

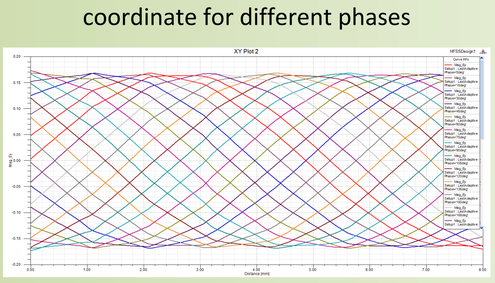




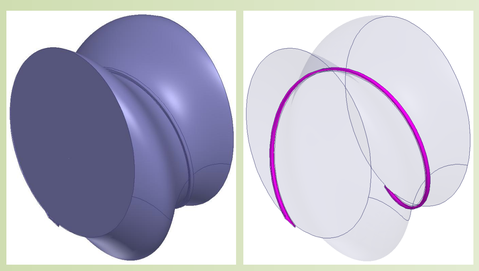
Transverse field components vs longitudinal coordinate for different phases



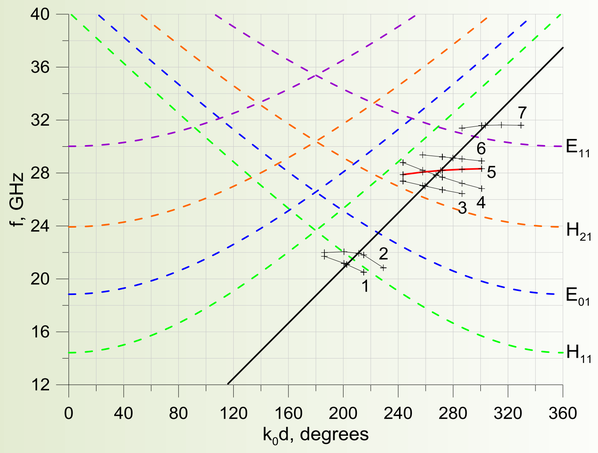
Phases of electric field components at beam line
1 - Phase of accelerating component
2,3 - Phases of transverse components



Accelerating field component vs longitudinal coordinate for different phases



Groove with absorber is parallel to surface currents of operating eigen mode only

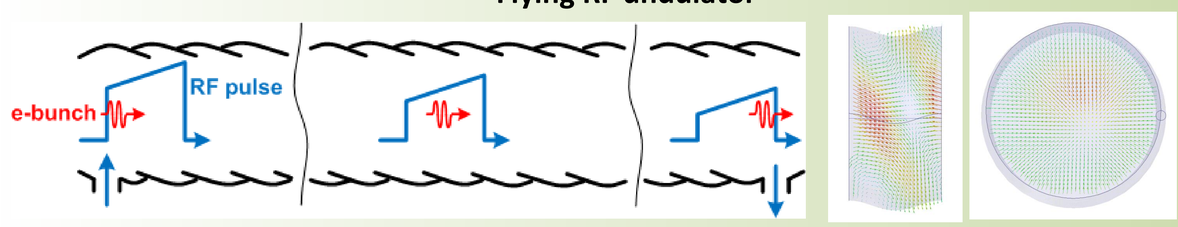


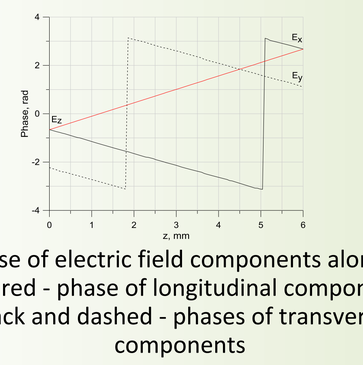
Dispersion of modes could be exited by electron beam

Table of modes in helical accelerating structure with mode selection (absorption groove)

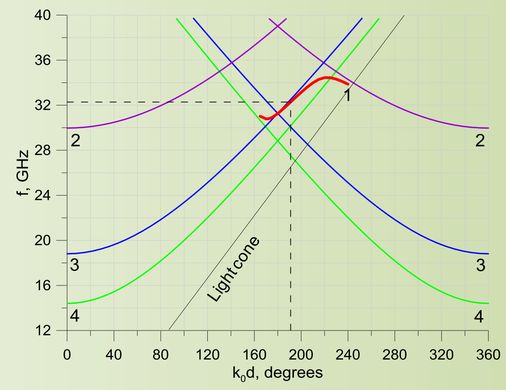
№	Mode	Rotation	ϕ , rad	ϕ , deg	f_0 , Ghz	Q_0	f*, GHz	Q*
1	$H_{11}+E_{01}$	ccw	3.5346	202.51	21.0869	9255	21.0862	2607
2	$H_{11}+E_{01}$	cw	3.687	211.25	21.9336	8832	21.9368	3464
3	$H_{21}+H_{11}$	ccw	4.53	259.55	27.0125	7141	26.9984	1650
4	$H_{21}+H_{11}$	cw	4.67	267.57	27.8435	7869	27.8277	2623
5	$E_{11}+E_{01}$	ccw	4.727	270.83	28.1930	10824	28.1938	7168
6	$E_{11}+E_{01}$	cw	4.885	279.89	29.1356	9940	29.1345	6391
7	?	?	5.2975	303.52	31.6039	14856	31.5939	3004

Flying RF undulator

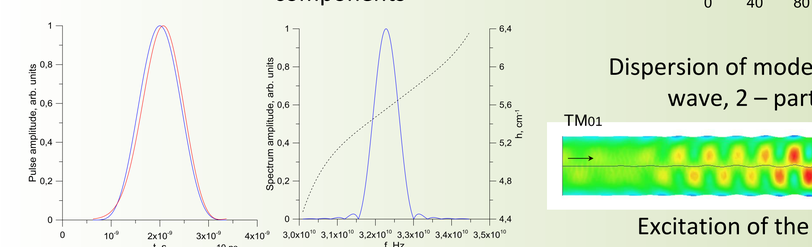




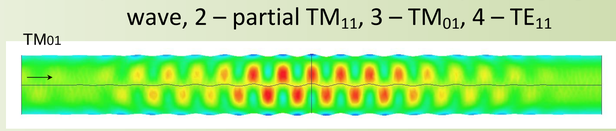
Phase of electric field components along z axis: red - phase of longitudinal component, black and dashed - phases of transverse components



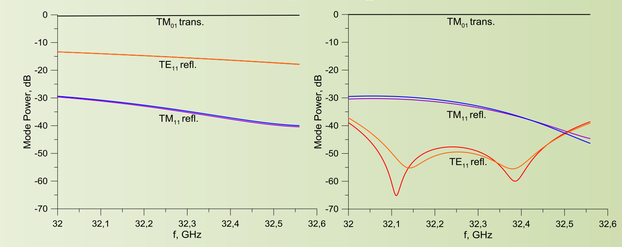
Dispersion of modes: 1 - TM_{01}-TM_{11} operating eigen wave, 2 – partial TM_{11}, 3 – TM_{01}, 4 – TE_{11}



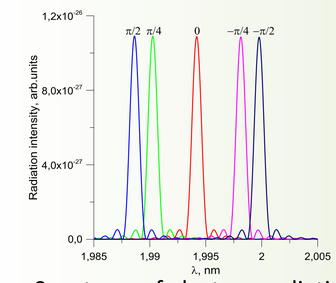
Simulation of pulse propagation in long helical waveguide.



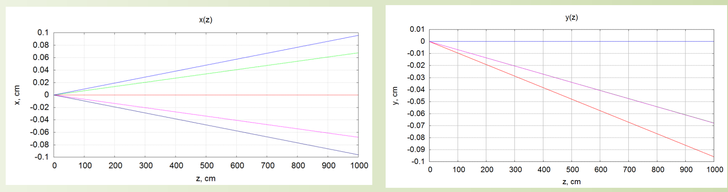
Excitation of the operating mode with taper



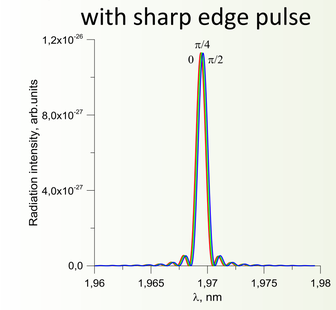
Efficiency of taper: left – 5 periods taper, right – 10 periods taper



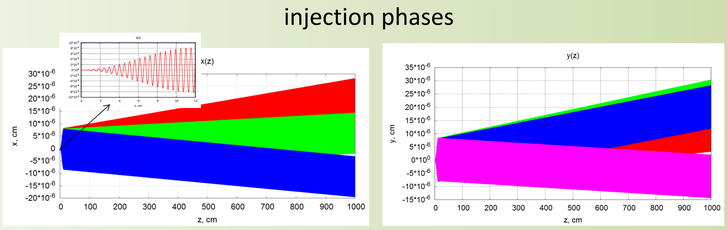
Spectrum of electron radiation with sharp edge pulse



Simulation of electron trajectory in sharp edge pulse with different injection phases

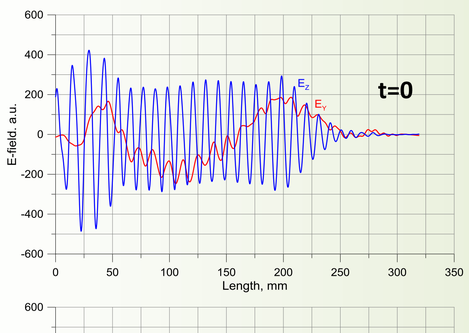


Spectrum of electron radiation with soft edge pulse

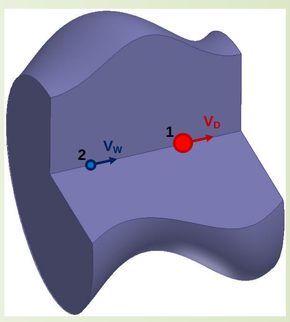


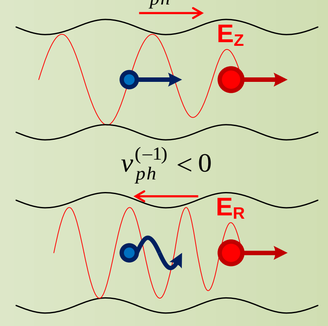
Simulation of electron trajectory in soft edge pulse with different injection phases

Flying RF undulator excited by drive bunches



Simulation of pulse excited by three space-periodic drive bunches in different time

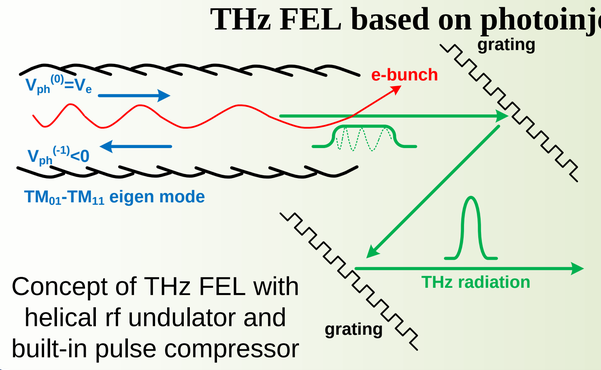




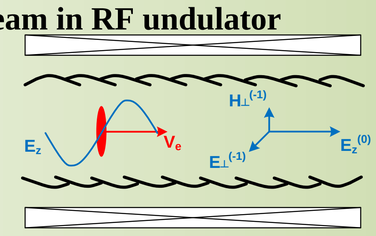
Excitation of RF pulse by drive bunch

Drive bunch due to Cerenkov synchronism excites slow eigen mode of the helical waveguide with positive group velocity. The -1st space harmonic has negative phase velocity and provides wiggling of electrons with high Doppler's frequency up-shift.
Effective undulator might be infinitely long.

THz FEL based on photoinjector beam in RF undulator



Concept of THz FEL with helical rf undulator and built-in pulse compressor



RF undulator based on helical waveguide. 0th space harmonic prevents bunch expansion longitudinally, -1st harmonic provides wiggling.