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Superconductive Undulators: Mechanical deviations and their influence on the phase error

D. Wollmann, University of Karlsruhe, Germany

Introduction

- Due to constructive interference of photons emitted by a single electron passing through an undulator magnetic field, the undulator emits a line spectrum:

$$\lambda_L = \frac{\lambda_u}{2k\gamma^2}\left(1+\frac{K^2}{2}\right). \qquad (1)$$

with the period length λ_u, the relative beam energy γ, the harmonic number of the emitted radiation k ($k = 1, 3, 5, ...$), the deflection parameter $K = 0.0934 \cdot \lambda_u[mm] \cdot \tilde{B}[T]$ and the amplitude of the magnetic field $\tilde{B}$.

- In superconductive undulators the alternating field is produced by two coils

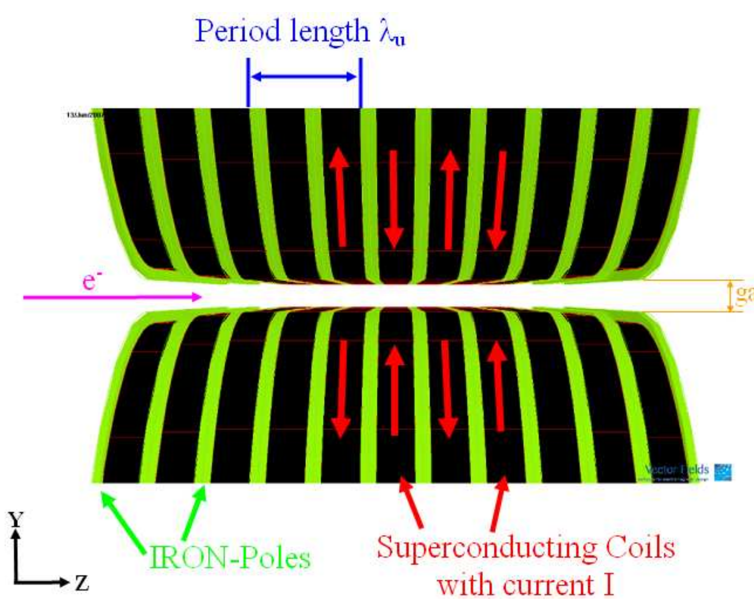

Figure 1: Opera3d [1] modell of a superconductive undulator with iron poles and superconductive wire bundels

- For a given gap and a given period length superconductive undulators have a higher field strength compared to permanent magnet undulators

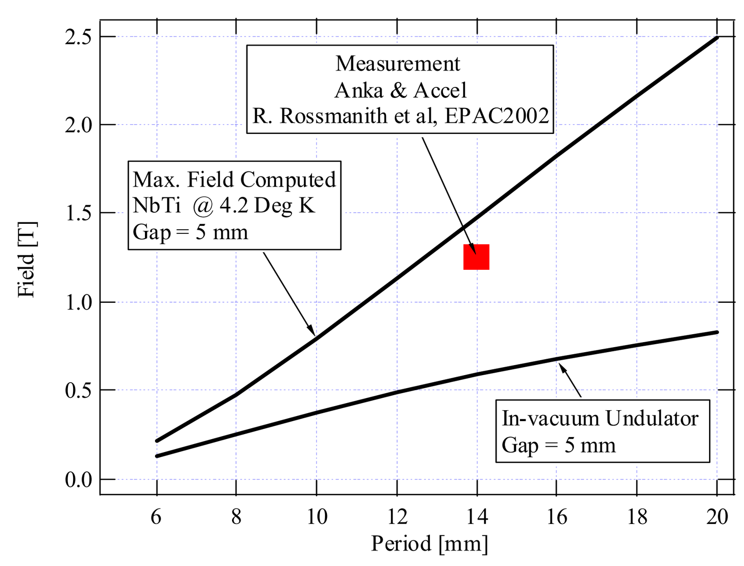

Figure 2: Comparison of the achievable calculated max. field strength for superconductive NbTi and in-vacuum permanentmagnet undulators [2].

Phase requirements

- To obtain the maximum brilliance a constant difference between the phase of the emitted photon and the phase of the oscillating electron in each undulator period is required.
- A phase slip between the electron and the photon would disturb the constructive interference and, thus, cause a broadening and intensity reduction of the emission lines
- Therefore field errors of undulators have to be corrected

Phase difference between photon and electron for the period i:

$$\Phi_i = \frac{2\pi}{\lambda_u}\left(\frac{2(\frac{e}{m_e c})^2 J(z_i) - K^2(z_i - z_0)}{2+K^2}\right), \qquad (2)$$

with

$$J(z_i) = \int_{z_0}^{z_i}\left(\int_{z_0}^{z} B_y(z')dz'\right)^2 dz.$$

$B_y(z)$, the y-component of the magnetic field along z.

Phase error for an undulator with n periods:

$$\Phi_{error} = \sqrt{\frac{\Sigma_{i=1}^{n}(\Phi_i)^2}{n}}. \qquad (3)$$

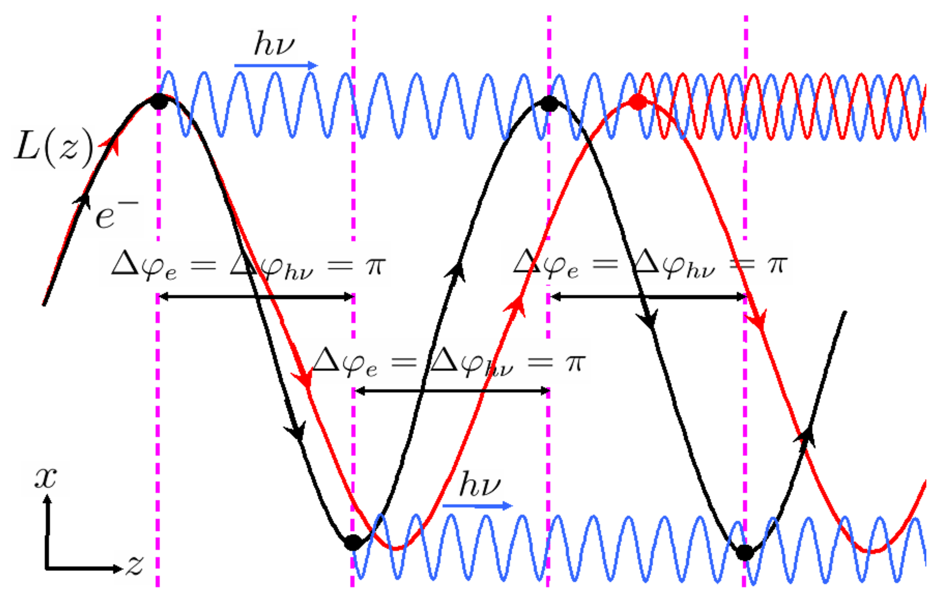

Figure 3: The variation of the period length or the amplitude of the magnetic field causes a slip between the electron phase and photon phase. In the worst case this leads to destructive interference.

Mechanical deviations

- In superconductive undulators phase errors are caused by mechanical deviations of the pole position and the position of the wire bundle relative to the gap center (y-direction).

Pole deviations

- The displacement of a pole in y-direction causes a local field disturbance

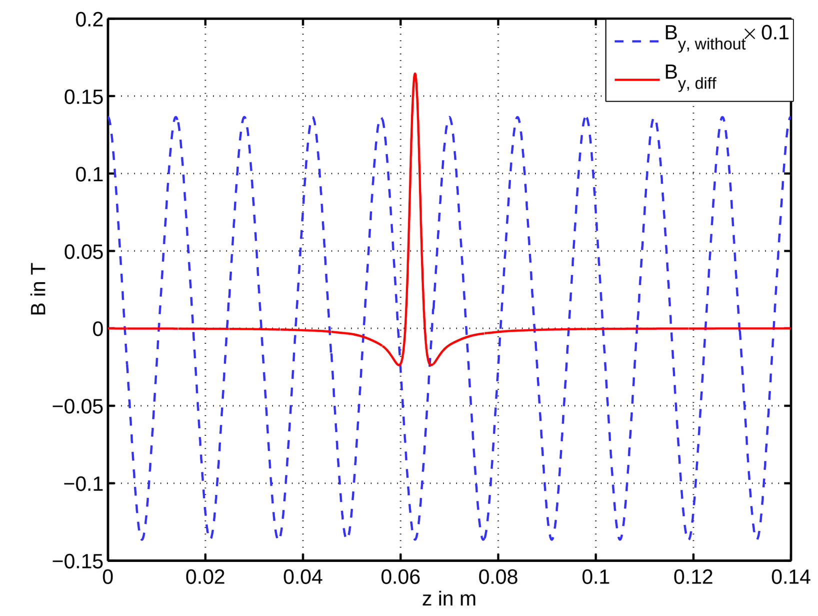

Figure 4: Field deviation caused by the mechanical displacement of one pole ($500\mu m$ in y-direction).

Wire bundle deviations

- The displacement of a wire bundle in y-direction causes an anti-symmetric local field disturbance

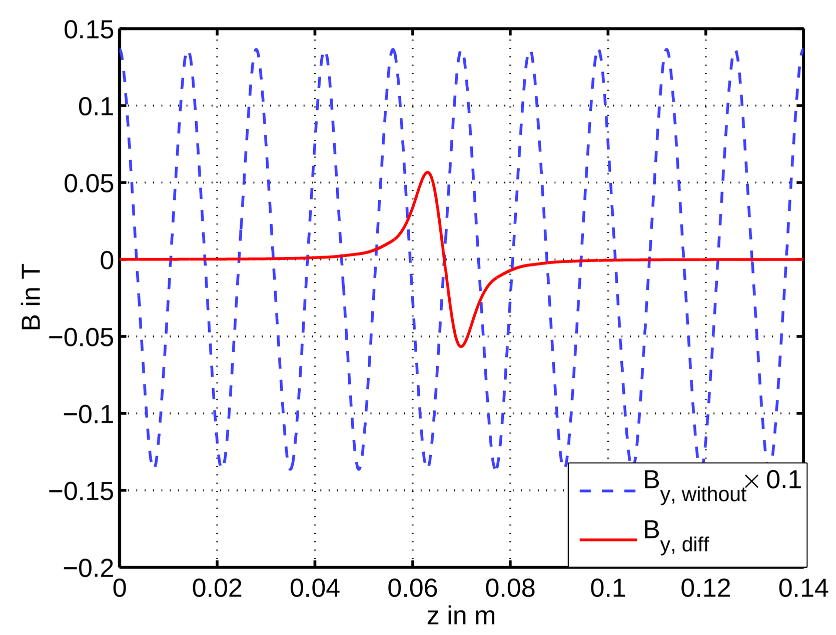

Figure 5: Field deviation caused by the mechanical displacement of one wire bundle ($500\mu m$ in y-direction).

Monte-Carlo simulations

- Mechanical deviations of the poles and the wire bundles can be assumed as normally distributed along the undulator, due to the given mechanical tolerances in the construction process.
- Therefore the phase errors of different undulators constructed with the same mechanical tolerances vary.
- The required mechanical tolerances to obtain a specific phase error, can be achieved by Monte-Carlo-simulations with several thousand undulators.

(50 periods, $\lambda_u = 14mm$, $\tilde{B} = 1.24T$, 1000 undulators)

Variation	Φ_{error} (pole)	Φ_{error} (conductor bundle)
5 μm	$0 - 4^o$	$0 - 1.5^o$
14 μm	$1.5 - 10^o$	$1.5 - 4.5^o$
50 μm	$10 - 100^o$	$5 - 15^o$

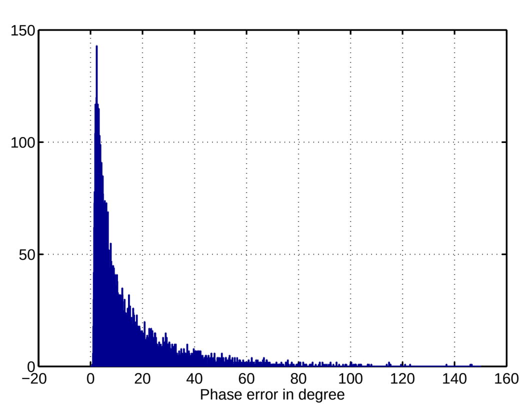

Figure 6: Monte-Carlo simulation of 10000 undulators with normally distributed pole and coil displacement ($5\mu m$ in y-direction).

Acknowledgments

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References

[1] Vector Fields Ltd. Software for electromagnetic design.

[2] Pascal Elleaume, editor. *Workshop on superconducting Wigglers and Undulators.* ESRF, 2003.