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Numerical Design Optimization of Short-Period HTS Staggered Array Undulators

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ID: Wed-Af-Po3.16-06 [24] - Magnet Technology Conference 26 – Vancouver, Canada

Introduction

Short-period and high field undulators are essential components for future compact free electron lasers (FEL) and other X-ray sources

***Re*BCO bulk materials or stacked *Re*BCO tapes in a staggered array geometry can easily outperform what can be achieved with permanent magnets, wound copper coils or even LTS wire-based undulators**

Simulation Model

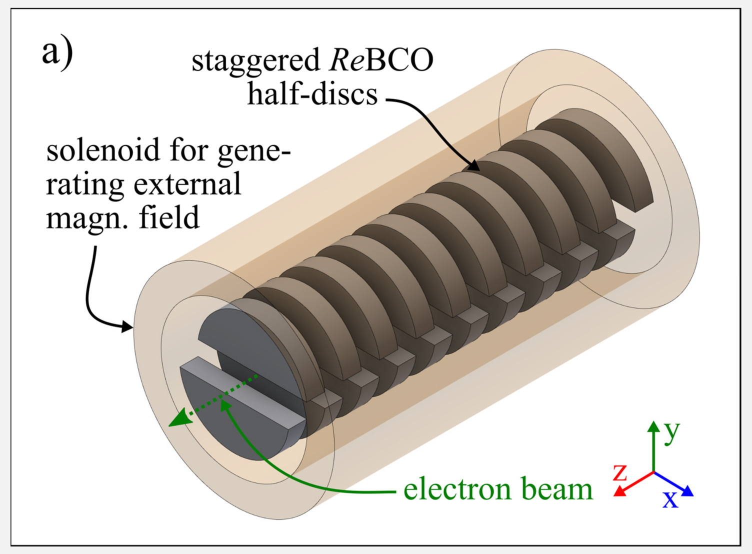
The resistivity of the superconducting domains is defined via the power-law

$$\rho_{sc}(J,B) = \frac{E_c}{J} \cdot \left(\frac{J}{J_c(B)}\right)^n$$

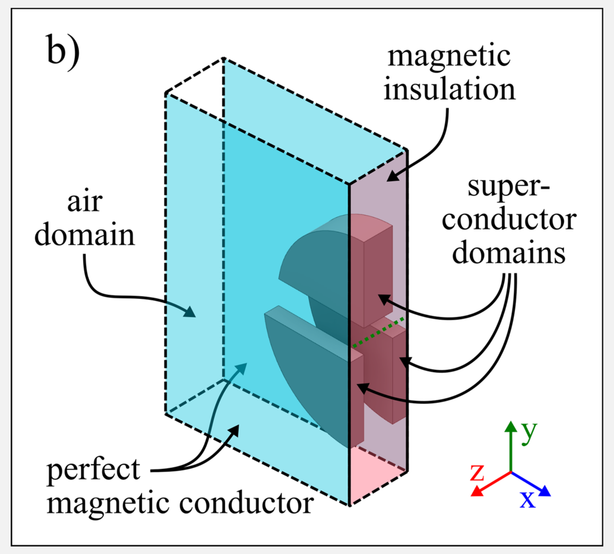
with n = 20 and
E_c = 1 µV/cm

The model is implemented in the commercial FEM software tool COMSOL Multiphysics® using the *H*-formulation

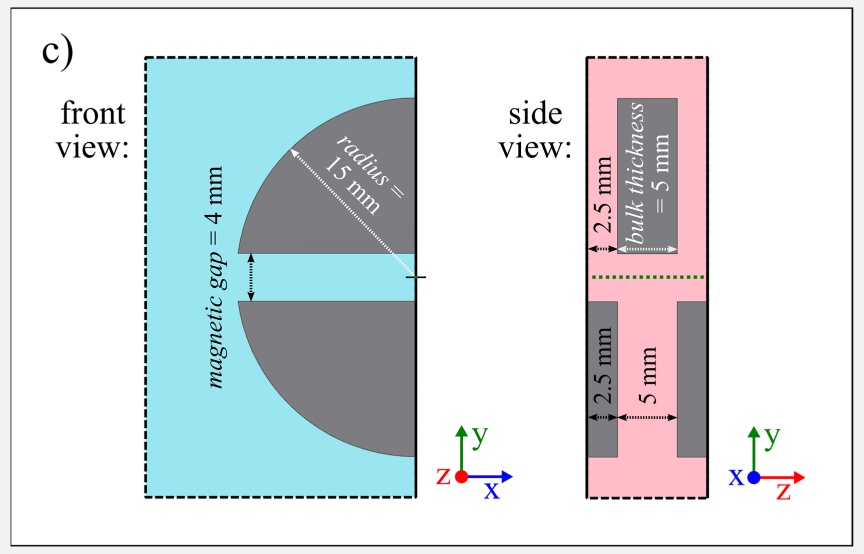
"Full" staggered array undulator geometry



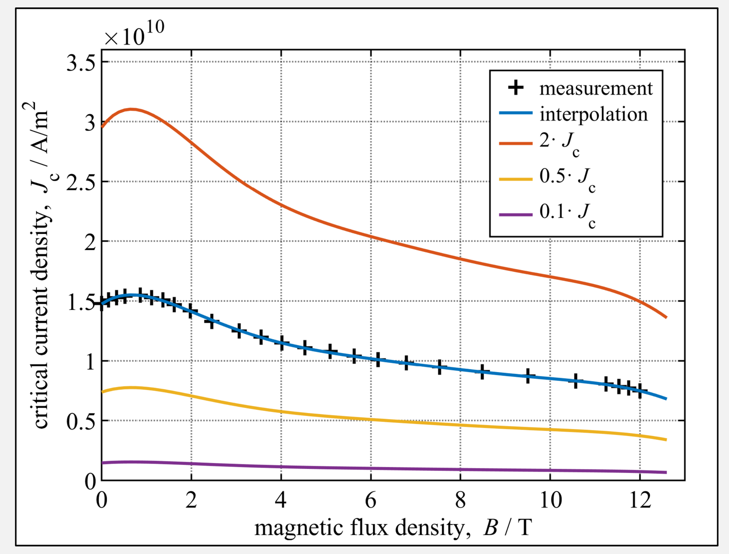
Single-period undulator simulation model



Reference undulator geometry for comparison during optimization process

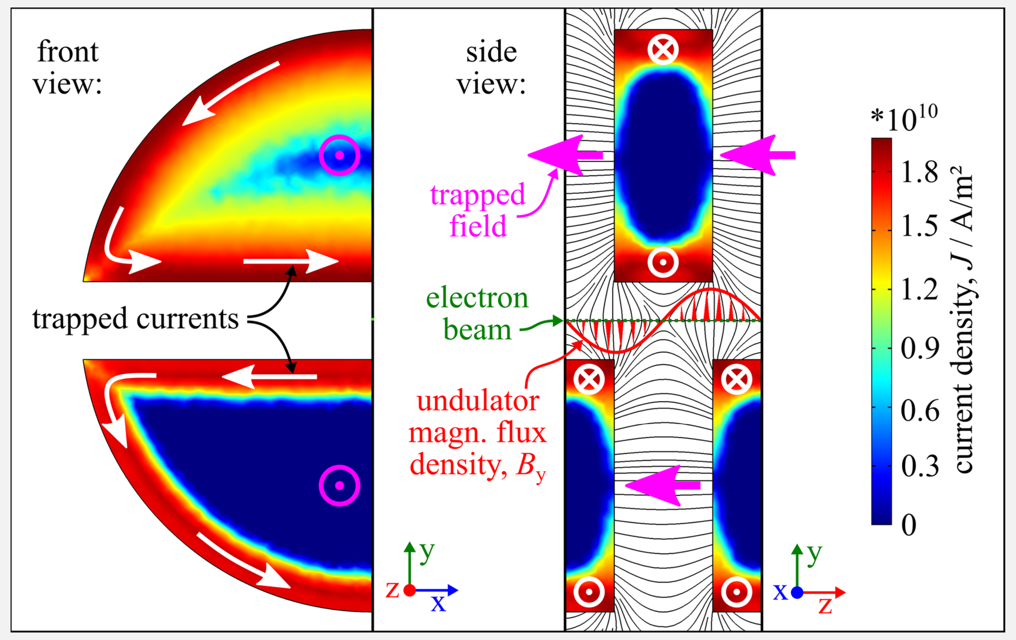


Scaled critical current density $J_c(B)$ for superconductor domain



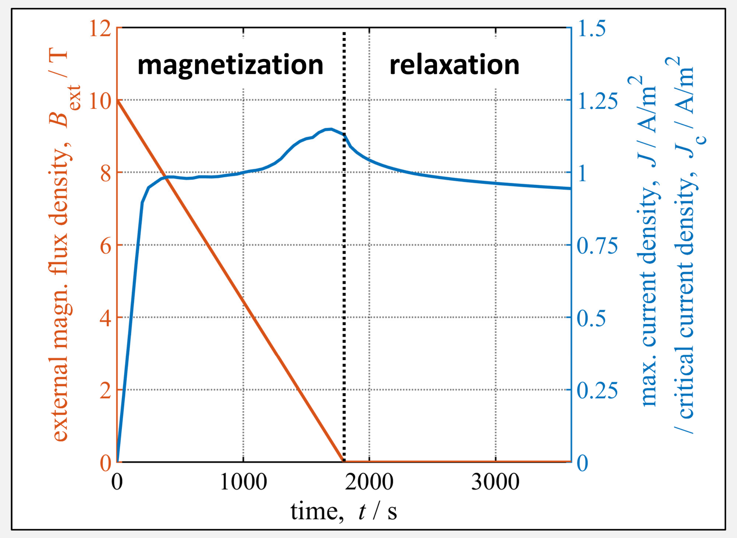
Undulator Functional Principle

Trapped currents inside *Re*BCO bulk pieces after field-cooling (FC) magnetization from 10 T to 0 T in 5 s



The undulator field, B_y in the staggered array undulator is created by the stray components of the main trapped field traversing between the upper and lower row of *Re*BCO bulks

Relative trapped currents inside *Re*BCO bulk pieces during field-cooling (FC) magnetization from 10 T to 0 T in 1800 s and during additional 1800 s relaxation time



Trapping currents above the critical current density J_c is possible in the flux-creep model. This especially applies for short magnetization times.

Over-trapped currents decay significantly faster due to the highly nonlinear characteristics of the power-law

Parameter Sweeps

The numerical design optimization is achieved via parameter sweeps over the three geometry parameters:

1. **The *Re*BCO bulk thickness, *t***
2. **The *Re*BCO bulk radius, *r***
3. **The magnetic gap, *g***

In addition, three different magnetization schemes are used to apply the external magnetic flux density (solenoid) in the simulation model:

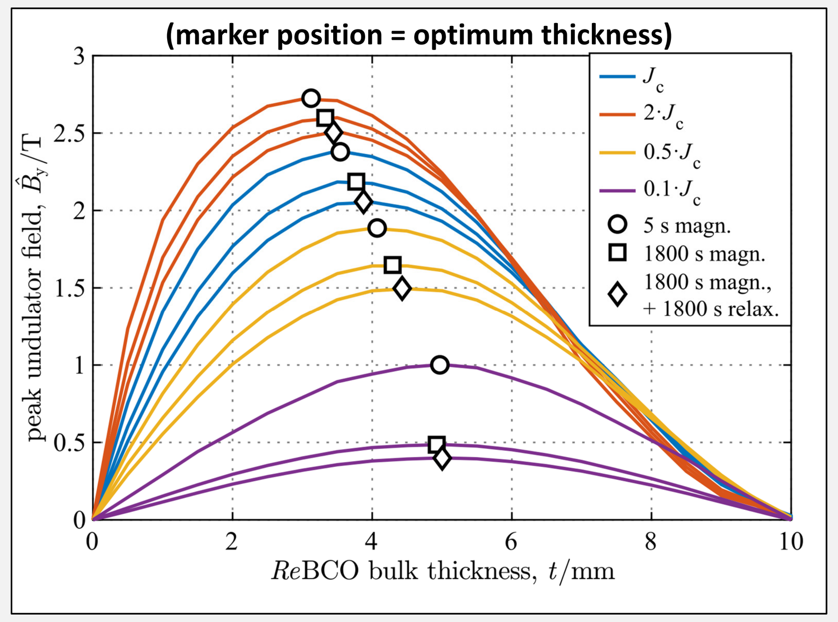
a. **FC from 10 T → 0 T in 5 s (theoretical reference)**
b. **FC from 10 T → 0 T in 1800 s**
c. **FC from 10 T → 0 T in 1800 s plus 1800 s relaxation time with no extern field applied**

The critical current density $J_c(B)$ is scaled in the parameter sweep to represent a wider range of available *Re*BCO bulk materials:

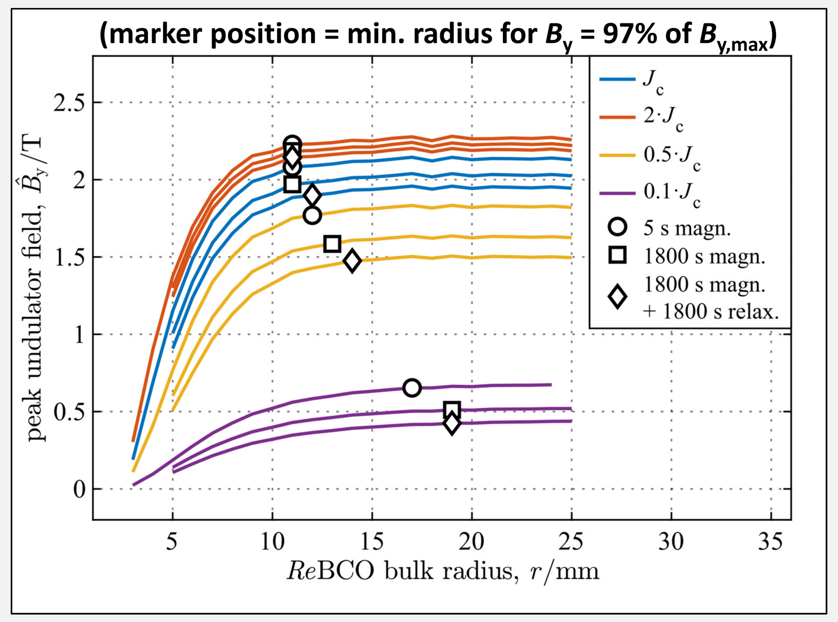
a. **1 · $J_c(B)$**
b. **2 · $J_c(B)$**
c. **0.5 · $J_c(B)$**
d. **0.1 · $J_c(B)$**

Results

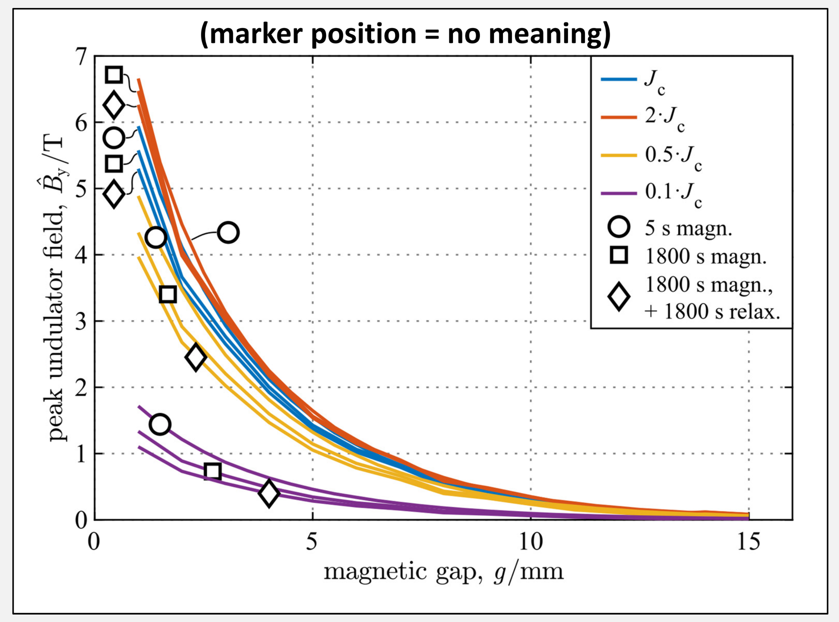
1. Parameter sweep over the *Re*BCO bulk thickness, *t*



2. Parameter sweep over the radius, *r* of the *Re*BCO bulk half-discs



3. Parameter sweep over the magnetic gap, *g* between the upper and lower *Re*BCO half-discs



Conclusion

The results of this simple parameter sweep allow a deeper understanding of the complex correlation between the different geometry parameters of a staggered undulator geometry

They can be used to determine the optimum *Re*BCO bulk dimensions while reducing the amount of SC-material and solenoid aperture

In the presented case we would suggest *t* = 4 mm, *r* = 13 mm for *g* = 4 mm and a critical current density of 1 · $J_c(B)$