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”wakis”: An Open-Source 3D Time-Domain Electromagnetic Solver for Beam-Coupling Impedance Calculation

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In the field of accelerator physics, the determination of electromagnetic wakefields and their impact on accelerator performance remains a critical challenge. These wakefields, generated within the accelerator vacuum chamber by the interaction between the structure and a passing beam, significantly influence machine behavior. Characterizing these effects through beam-coupling impedance is essential for predicting power dissipation and maintaining beam stability. For simple structures, beam-coupling impedance can be computed using analytical formulas. However, realistic accelerator devices require full-wave 3D numerical soluctions of Maxwell's Equations. In the framework of CERN's open science mission, this paper presents “wakis”, an open-source 3D electromagnetic time-domain solver designed to compute wake potential and impedance for both longitudinal and transverse planes in general 3D structures. Fully implemented in Python, the tool includes features such as the incorporation of material tensors (permittivity, permeability, conductivity) with support for anisotropy, and a CAD geometry importer (.stl format) for defining embedded boundaries and material regions. It supports various boundary conditions including PEC, PMC, periodic, ABC-FOEXTRAP, and multiple time-domain sources such as particle beams with custom profiles, plane waves, and wave packets. The fully exposed API allows dynamic modification of material tensors and fields during simulations, leveraging NumPy and SciPy sparse routines for efficient calculations. Additionally, “wakis” offers on-the-fly 1D, 2D, and 3D vtk-based plotting capabilities, optimized memory consumption, and GPU acceleration via CuPy/CuPyx. “wakis” is under continuous development on GitHub, aiming to provide an open-source platform for the community to collaboratively address future accelerator challenges and surpass current software limitations.

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