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Application of automatic differentiation based ptychography for single-shot SASE FEL beams characterization

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Wavefront sensing and characterization of the spatial and coherent properties of the Free-Electron-Lasers (FELs) radiation is vital for experiment planning, beamline optics alignment and the photon diagnostics. At the Free-electron LASer at Hamburg (FLASH), the Hartmann wavefront sensing is a typical technique used for the single-shot beam characterization. However, it is working in the assumption of the fully spatially coherent radiation and has resolution limited by mechanical components. Ptychography is another promising technique, which can provide us with high resolution complex wavefields of the FEL radiation.

Ptychography is a scanning coherent diffraction imaging technique, which utilizes mutual overlap between neighboring scan positions for enforcing of the additional constraints during the reconstruction. These constraints make it robust and free of the reconstruction artifacts possible in the other CDI techniques. Ptychography allows to reconstruct complex sample function together with the complex wavefield of the illumination with diffraction limited resolution, and thus, it is frequently used for the beam characterization purposes.

Typically, ptychographical reconstruction assumes constant illumination, and can treat partially coherent illumination by usage of multimodal beam assumption. However, in this case, modal composition also should be constant for each shot, and spatial shot-to-shot fluctuations should be minimized. This conditions cannot be easily fulfilled at Self-Amplified Spontaneous Emission (SASE) FELs with their fluctuating and partially spatially coherent beams.

In this work, we suggest to use a novel automatic differentiation (AD) based ptychographical engine which is able to perform reconstructions under these conditions. AD allows to split ptychographical algorithm into independent forward model, which can be flexibly changed, and optimization routine. This flexibility allows to adapt the forward model to the specifics of ptychographical experiments at SASE FEL and to perform the reconstructions in the assumption of multi-modal spatially fluctuating illumination, with the unique modal composition for each individual shot.

We present an AD-based ptychographical engine applicable for ptychography at FELs. With its help we were able to reconstruct complex wavefields of the FLASH2 radiation during the ptychographical measurements. Applications of AD-based ptychography to beam characterization and possibility of reconstruction of individual shots characteristics will be discussed.

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