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Optimization of vortex pinning by nanoparticles using simulations of the time-dependent Ginzburg-Landau model

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Incorporating nanoparticles into superconducting materials has been established as an efficient route to enhance their current-carrying capability. We explored vortex pinning by randomly distributed spherical nanoparticles using large-scale numerical simulations of time-dependent Ginzburg-Landau equations. First, we investigated a vortex lattice interacting with an *isolated* defect [1]. We found a series of first-order phase transitions at well-defined magnetic fields, when the number of vortex lines occupying the inclusion changes. The pin-breaking force has sharp local minima at those fields. As a consequence, in the case of isolated identical large-size defects, the field dependence of the critical current is composed of a series of peaks located in between the occupation-number transition points. Furthermore, exploring the magnetic-field dependences of critical current for superconductors containing *finite density* of spherical inclusions with different sizes, we found several pinning regimes that indeed are mostly characterized by the average occupation numbers of inclusions with the vortex lines[2]. The distinct peak effect, however, only exists for very small inclusion densities when the vortices form a regular lattice. Finally, we also found optimal size and density of particles, which maximize the critical current for fixed magnetic field[3]. For every particle size, the critical current reaches maximum value at certain particle density, typically corresponding to 15-22% of the volume fraction filled by the particles. Moreover, we found that, as the magnetic field increased, the optimal particle diameter slowly decreases from 4.5 to 2.5 coherence lengths. This result shows that pinning landscapes have to be designed for specific applications taking into account relevant magnetic field scales.
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[2] *Strong pinning regimes by spherical inclusions in anisotropic type-II superconductors*, R. Willa, A. E. Koshelev, I. A. Sadovskyy, and A. Glatz, Sup. Sci. Techn., **31**, 014001(2018).
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Primary author: Dr KOSHELEV, Alexei (Materials Science Division, Argonne National Laboratory)

Co-authors: Dr WILLA, Roland (Institute for Theory of Condensed Matter, Karlsruhe Institute of Technology); Dr SADOVSKYY, Ivan (Station Q, Microsoft Research); Dr GLATZ, Andreas (Materials Science Division, Argonne National Laboratory)

Presenter: Dr KOSHELEV, Alexei (Materials Science Division, Argonne National Laboratory)

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