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Creep effects on the Campbell response in type II superconductors

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Applying the strong pinning formalism to the mixed state of a type-II superconductor, we study the effect of thermal fluctuations (or creep) on the penetration of an ac magnetic field as quantified by the so-called Campbell length λ_C. Within strong pinning theory, vortices get pinned by individual defects, with the jumps in the pinning energy (e_{pin}) and force (f_{pin}) between bistable pinned and free states quantifying the pinning process. We find that the evolution of the Campbell length $\lambda_C(t)$ as a function of time t is the result of two competing effects, the change in the force jumps $f_{\mathrm{pin}}(t)$ and a change in the trapping area $S_{\mathrm{trap}}(t)$ of vortices; the latter describes the area around the defect where a nearby vortex gets and remains trapped. Contrary to naive expectation, we find that during the decay of the critical state in a zero-field cooled (ZFC) experiment, the Campbell length $\lambda_C(t)$ is usually nonmonotonic, first decreasing with time t and then increasing for long waiting times. Field cooled (FC) experiments exhibit hysteretic effects in λ_C; relaxation then turns out to be predominantly monotonic, but its magnitude and direction depend on the specific phase of the cooling-heating cycle. Furthermore, when approaching equilibrium, the Campbell length relaxes to a finite value, different from the persistent current, which vanishes at long waiting times t, e.g., above the irreversibility line. Finally, measuring the Campbell length $\lambda_C(t)$ for different states, zero-field cooled, field cooled, and relaxed, as a function of different waiting times t and temperatures T , allows to spectroscopyse the pinning potential of the defects.