Shortcuts to Isothermality: Speeding up Heat Engines by Strong Coupling

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Quasi-static thermodynamic transformations are minimally dissipative but also slow processes, as the system needs to remain close to thermal equilibrium along the protocol. This requires the total time of the process to be longer than the time scale of thermalisation between the system of interest and the thermal environment. Naively, these processes can then be speeded-up by increasing the coupling between system and environment. However, modifying the coupling also increases dissipation, which avoids the non-physical possibility of making an isothermal process arbitrarily fast. Given this non-trivial tradeoff, here we develop protocols that gently modify the system-bath interaction in order to keep the overall dissipation constant while decreasing the total time of the thermodynamic protocol. For such improved quasi-static processes, we show that the dissipation $W_{\rm dis}$ decays with the total time of the protocol τ as $W_{\rm dis} \propto \tau^{-2\alpha-1}$ with $\alpha = 1, 2, ...$; which should be contrasted to the standard decay with $\alpha = 0$ when the system-bath interaction remains constant during the protocol. When considering heat engines based on such shortcuts to isothermality, we show that each decay with α leads to a new efficiency at maximum power, which interpolates between the Curzon-Ahlborn efficiency for $\alpha = 0$ and the Carnot efficiency for $\alpha \to \infty$. These considerations are illustrated in the Caldeira-Legget model, which we simulate exactly at arbitrarily strong coupling by considering a large-but-finite bath to ensure that all sources of dissipation are accounted for.