Performance in finite time for quantum heat engines

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The Carnot cycle has the highest efficiency, but it outputs zero power because it requires infinite time to output a finite amount of work. Thus, research into the performance in finite time for heat engines has attracted great interest and seen much progress. The previous literature takes for granted that an adiabat costs no time compared with an isothermal process. This assumption is justified in classical mechanics but not so in quantum mechanics, since the time scale of the change in the quantum state of the system with energy \( E \) must be much larger than the time scale, \( \sim \frac{E}{\hbar} \). Nonadiabatic dissipation (e.g., inner friction) would occur if the change in the energy-level structure of the quantum system is rapid (in comparison with the time scale, \( \sim \frac{E}{\hbar} \)).

Here, we suggest a new approach to study the finite time performance of a quantum heat engine cycle that includes both time spent on quantum adiabatic process and nonadiabatic phenomenon. Based on the fact that the external parameter affecting the energy spectrum varies at a small but fixed speed, we derive the cycle period which consists of times spent both on the two quantum isotherms and on the two adiabatic processes. By varying the time allocation of the four thermodynamic processes, the performance of the quantum heat engines is optimized and a universal behavior of the efficiency at maximum power output is identified.