Finite-power performance of heat engines in the linear response regime

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Within the framework of linear irreversible thermodynamics, Izumida recently introduced the thermodynamic description of local equilibrium to the endoreversible Carnot-like cycle consisting of two adiabatic and two isothermal processes, where the heat conduction is assumed to be phenomenological Fourier law. Nevertheless, the local equilibrium thermodynamic description to a quantum heat engine cycle (not restricted to Carnot-like one), and a unified framework for the study of finite-power quantum engines satisfying the endoreversible condition within linear irreversible thermodynamics, is still lacking. For this reason, we study the finite-power performance of a generalized quantum engine cycle based on the local equilibrium assumption, revealing the possibly universal bound of the efficiency at maximum power. Without loss of generality, the working substance of the heat engine is composed of harmonic oscillators and spin-1/2 particles, two types of particles in the universe: bosons and fermions.

We analyze a general model of quantum heat engine operating a cycle of two adiabatic and two thermal processes, where the working substance is composed of a harmonic or spin system. We apply the local equilibrium description to the heat engine cycle working in the linear response regime and derive the expressions of the efficiency and the power. By analyzing the entropy production rate along a single cycle, we identify the thermodynamic flux and force which a linear relation connects. From maximizing the power output, we find that such heat engines satisfy the tight-coupling condition and the efficiency at maximum power agrees with the CA efficiency known as the upper bound in the linear response regime.

Our approach is quite general because (except for use of local equilibrium assumption) it does not demand any particular system as its working substance obeys any one of the two typical quantum statistics (Fermi-Dirac and Bose-Einstein)and does not employ any specific law(s) of thermal conduction.

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