Energy harvesting from anisotropic fluctuations

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In contrast to the classical concept of a Carnot engine that alternates contact between heat baths of different temperatures, naturally occurring processes usually harvest energy from anisotropy, being exposed simultaneously to chemical and thermal fluctuations of different intensities. In these cases, the enabling mechanism responsible for the transduction of energy is typically the presence of a non-equilibrium steady state (NESS). A suitable stochastic model for such a phenomenon is the Brownian gyrator – a two-degree-of-freedom stochastically driven system that exchanges energy and heat with the environment. In the context of such a model, we present a geometric view of the energy harvesting mechanism that entails a forced periodic trajectory of the system state on the thermodynamic manifold. We show that path-lengths traversed in the manifold of thermodynamic states, measured in a suitable Riemannian metric, represent dissipative losses, while area integrals of a work-density quantify work being extracted. Thus, the maximal amount of work that can be extracted relates to an isoperimetric problem, trading off area against length of an encircling path. We derive an isoperimetric inequality that provides a universal bound on the efficiency of all cyclic operating protocols, and a bound on how fast a closed path can be traversed before it becomes impossible to extract positive work. The analysis presented provides guiding principles for building autonomous engines that extract work from anisotropic fluctuations.

References

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