Fluctuation theorems for an ideal and frictional granular motor

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One hundred years ago Marian Smoluchowski published the first explanation as to why a brownian ratchet cannot convert thermal fluctuations in a system in thermal equilibrium into useful work, in apparent violation of the second law of thermodynamics. The device was later popularised in the celebrated Feynmann Lectures on Physics and has continued to fascinate scientists ever since. In the last few years several theoretical and experimental studies of granular motors have been published. These devices can be considered as macroscopic realizations of the brownian ratchet with the important difference that the bath of granular gas that drives the motor is not at thermal equilibrium. If some asymmetry is present, the motor is capable of rectifying the random fluctuations of the bath particles.

A simple model granular motor consists of a heterogeneous piston composed of materials with two different coefficients of restitution which is immersed in a granular gas with a specified velocity distribution. Collisions with the gas particles induce a net motion of the piston together with large fluctuations.

We present a kinetic theory description of this model starting from the Boltzmann-Lorentz equation and apply it to investigate the applicability of fluctuation theorems of the form

$$\log\left(\frac{P(x_\tau = x)}{P(x_\tau = -x)}\right) = Cx,$$

where x_τ is the work, heat or entropy fluctuation in time τ and C is a prefactor, to an ideal granular motor and one where friction is present.