SIMULATION OF FUNCTIONING OF AN ADIABATIC BROWNIAN RATCHET DRIVEN BY SMALL SINUSOIDAL FLUCTUATIONS OF THE NANOPARTICLE POTENTIAL ENERGY

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We present some new results in modeling of Brownian ratchets, i.e. systems that can demonstrate a directional motion as a result of rectification of unbiased nonequilibrium fluctuations under the broken reflection symmetry [1]. In the theory of Brownian ratchets, the development of various approximations is a promising and fruitful method of obtaining analytical results and formulating generalized conclusions [2]. Among them is the approximation of small fluctuations of potential energy of a nanoparticle. Under the assumption, justified for many artificial ratchet systems, of separation of the potential energy into a stationary spatially periodic (L is a period) contribution, $u(x)$, and a small time-dependent perturbation, $\sigma(x)w(x)$, $U(x,t) = u(x) + \sigma(t)w(x)$, it turned out to be possible an elegant generalized integral representation of the average velocity of Brownian ratchets valid for arbitrary time laws $\sigma(x)$ [2,3]:

$$\langle v\rangle = L(\beta D)^2 \int_0^L dx \rho^{(+)}(x) w'(x) \int_0^L dy S(x,y) \tfrac{\partial}{\partial y} w'(x) \rho^{(-)}(y) \tag{1}$$

D is the diffusion coefficient, β is the inverse thermal energy, $\rho^{(\pm)}(x)$ is the Boltzmann distribution in the potential $\pm u(x)$. This representation is based on the subtask of finding the Green's function of the equation of diffusion in the stationary profile $u(x)$ which, together with the second-order autocorrelation correlation function of $\sigma(t)$, determines $S(x, y)$ [2,3].

Obtaining quantitative characteristics of a ratchet requires specification of the spatial-temporal dependencies of the potential energy. As $w(x)$-function, a sinusoidal (spatially harmonic) signal has been chosen, relevant for practical applications. If the shape of $u(x)$-function is not extremely asymmetric (a saw-tooth potential, a two-well potential of the hindered rotation, a potential of the two first harmonics, etc.), a construction of the Fourier analogue of the integral result becomes an effective strategy in modeling. We were interested in studying changes in behavior of stopping points and the multiplicativity (in terms of frequency-geometric parameters) of the structure of the velocity of ratchets with varying temperature and frequency of the perturbing signal. The adiabatic approximation and the choice of dichotomous time dependence of fluctuations allowed us to simplify the model to a one-dimensional sum over the Fourier components of controlling functions of the problem. We discuss a strategy of a choice of a phase shift of the perturbing signal, frequency and temperature, which are nonlinear mixed, for the control of the direction of Brownian ratchet motion. Graphic interpretations of the results obtained and recommendations on the organization of optimal modes of a ratchet have been given.

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